PROCEEDINGS OF THE SPACE SHUTTLE SORTIE WORKSHOP

VOLUME II

WORKING GROUP REPORTS

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REPORT OF THE SPACE TECHNOLOGY WORKING GROUP

CONTENTS

	Page
INTRODUCTION	1-1
ADVANCED TECHNOLOGY LABORATORY	1-2
LASER COMMUNICATIONS	1-8
EXTERNAL CONTAMINATION	1-11
DEVELOPMENT OF LOW-COST PAYLOAD TECHNOLOGY	1-13
ZERO GRAVITY OPTICAL TEST FACILITY	1-14
SPACE SHUTTLE FREE-FLYING EXPOSURE MODULE	1-18
SHUTTLE-BORNE ENTRY TECHNOLOGY EXPERIMENTS	1-36
CONCLUDING REMARKS	1-39
PHYSICS AND CHEMISTRY LABORATORY IN SPACE	1-41
APPENDIX A ADVANCED TECHNOLOGY LABORATORY	1-A-1
APPENDIX B LASER COMMUNICATIONS	1-B-1
APPENDIX C EXTERNAL CONTAMINATION	1-C-1
APPENDIX D DEVELOPMENT OF LOW-COST PAYLOAD TECHNOLOGY	1-D-1

CONTENTS (Continued)

	Page
APPENDIX E	
ZERO GRAVITY OPTICAL TEST FACILITY	1-E-1
APPENDIX F	
PARTICULATE MATTER IN SPACE (METEOROIDS, COSMIC DUST AND DEBRIS)	1-F-1
APPENDIX G	
ULTRAVIOLET METEOR SPECTROSCOPY FROM NEAR EARTH ORBIT	1-G-1
APPENDIX H	
MICROBIOLOGY (EXPLORATORY INVESTIGATIONS)	1-H-1
APPENDIX I	
MATERIALS, COMPONENTS AND SYSTEMS EXPOSURE EXPERIMENTS	1-I-1
APPENDIX J	
PHYSICS AND CHEMISTRY LABORATORY IN SPACE	1-J-1

REPORT OF THE SPACE TECHNOLOGY WORKING GROUP

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INTRODUCTION

Future applications, space science, and exploration flight programs will require advanced systems and low-cost operational techniques. Although much of this technology can be developed with ground-based facilities, some test conditions (i.e., high-altitude, high-velocity, weightlessness, radiation, and earth orbital perspective) cannot be adequately or economically simulated on the ground. It is the objective of this working group report to define the usefulness of the shuttle sortie mode to the accomplishment of this work.

Advanced technology research and development efforts are required to provide the basic design data needed by the designers and planners of advanced space vehicles and missions. This multidiscipline technological data base can subsequently be used to design structures, subsystems, components, and instrumentation for the applications and scientific disciplines. The multidiscipline nature of advanced space technology was apparent from the wide variety of research activities embraced by the members of this working group. Each of these research areas has been treated as a separate discipline in this report.

Although advanced space technology covered a wide variety of disciplines, two classes of missions were identified. The advanced technology, laser communications, and external contamination experiments would utilize the sortie laboratory. The development of low cost payload technology, zero gravity optical test facility, long duration exposure facility, and entry technology research experiments would utilize the shuttle to transport/deploy/retrieve objects or use the

*In the absence of Mr. Novik, Mr. Hook served as acting chairman for the preparation of this report, with assistance from W. Hayes, Hdq. OAST.

shuttle itself as a test bed. A typical mission schedule (Figure 1-1) shows that the long duration exposure facility and low cost payload technology experiments could fly on early shuttle missions since they are essentially passive payloads to be deployed from the shuttle payload bay and left in orbit. External contamination experiments will fly on all missions for the first 3 years to define the shuttle local external environment, and all missions thereafter having contamination sensitive experimental equipment. The laser communications experiment can be integrated with the advanced technology experiments which will utilize two missions per year beginning in 1980. Because of its size and experimental objectives, the optical test facility must be considered a quasi-dedicated payload. Entry technology experiments will be initiated in 1980 on a minimal or no-impact basis.

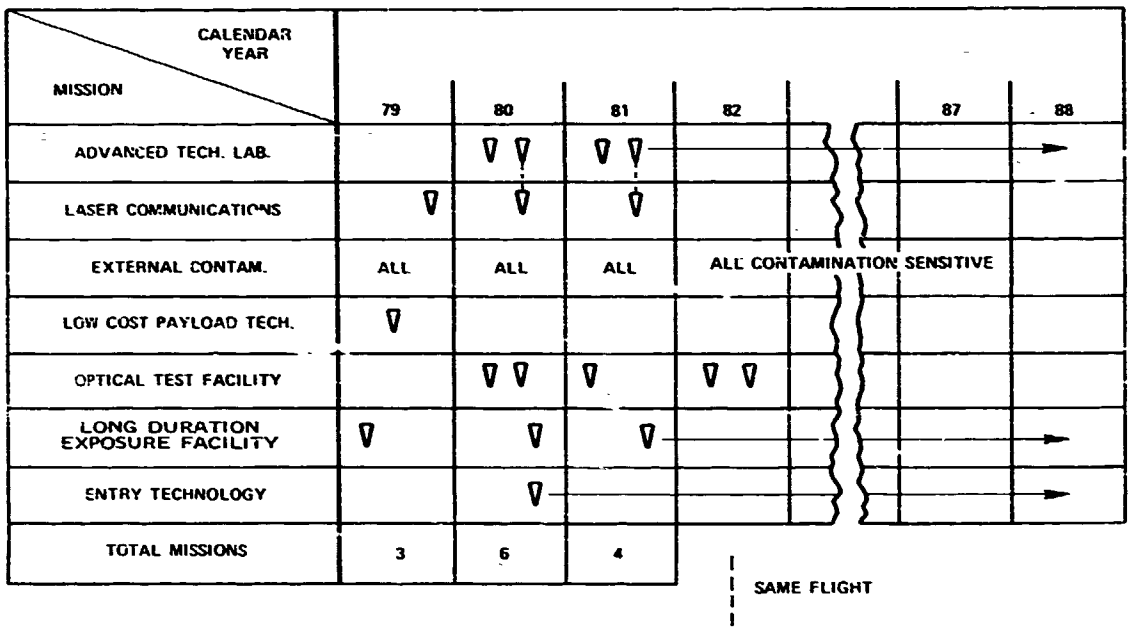

Figure 1-1. Space-Technology Sortie Schedule

ADVANCED TECHNOLOGY LABORATORY

An orbiting laboratory dedicated to the conduct of advanced research is a logical extension of present ground capabilities. The Langley Research Center (LRC) is conducting an in-house study to define an Advanced Technology Laboratory (ATL) particularly suited to LRC's technical expertise, including definition of its requirements, demonstration of technical feasibility, and development of detailed ground and flight equipment and facility requirements for a multidisciplinary advanced technology program.

DISCIPLINE AREA

Advanced Technology Laboratory

GOALS AND OBJECTIVES FOR THE 1980'S

An in-house NASA study has defined a shuttle-compatible Advanced Technology Laboratory (ATL) particularly suited to Langley Research Center's technical expertise and research requirements. An ATL is simply a standard sortie laboratory equipped with peculiar experimental equipment and made ready for an assigned shuttle sortie flight. This approach provides a clear division of responsibility and allows NASA to utilize its existing organization to plan, organize, develop, direct, and control its contribution to agency goals. In this way, a manageable advancing multidisciplinary-technology program can be maintained that will provide center researchers with routine access to space. As these advanced technology experiments are further refined along with the more specifically discipline-oriented applications and scientific experiments, it is recognized that some of the multidisciplinary experiments proposed here could be integrated into singular-discipline-oriented sortie Laboratories. However, the results of this LRC in-house study will provide an approach for accomplishing multidiscipline advanced technology experiments which can be evaluated by NASA management.

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

In this in-house study, experiments and the associated prospective Principal Investigators (P.I.) were identified at LRC alone. Due to the dynamic nature of research, these 30 experiments represent a snapshot in time of the space-oriented portion of the research evolving in NASA. Because of the multidiscipline nature of these advanced technology experiments and organizational and functional realignments with the agency, some of these experiments may also be reported by other working groups. Some of them, in fact, may now more appropriately be accomplished by P.I.'s at other centers. This overlap of experiments between working groups is considered to be unavoidable and even desirable at this time to ensure comprehensive results from the shuttle sortie workshop.

The following is a list of advanced technology experiments:

Communications and Navigation

- Microwave Interferometer Navigation and Tracking Aid — Objective: To determine the utility, limitations, and accuracy of a satellite interferometer

technique at L-band for locating low-powered radio sources on the earth and on moving vehicles under a variety of weather conditions.

- Microwave Radiometer Measurements — Objective: To develop and test new microwave components and techniques in low-earth orbit, to make day/night measurements of ocean temperature and sea state using microwave radiometers under varying meteorological conditions, and to measure R-F radiation from galactic sources.

- Precision Laser Ranging and Altimetry — Objective: To determine the utility, limitations, and accuracy of a mode-locked laser-ranging system to measure range, line-of-sight angles, and range rate; to evaluate the utility of on-board laser-ranging to measure range to within ±3 cm over ATL to ground distances; to isolate problems that may be associated with the use of laser ranging in the earth-space environment; and to determine optimal engineering parameters under various modes of operation and operating conditions.

- Autonomous Navigation — Objective: To determine the utility, limitations, and accuracy of a number of navigation techniques for determining orbital position relative to earth ground track under identical environmental conditions; to measure sensor accuracy and overall system error to aid in testing analytical error models under a variety of environmental conditions; and to flight test a holographic starfield and landmark tracker and ground beacon tracker.

- Microwave Altimetry — Objective: To determine the utility, limitations, and accuracy of a microwave altimeter for all-weather use in accurately measuring relative earth surface height variations; to determine the accuracy of measuring scattering cross-section density for different surface features and compositions falling within the altimeter target area; and to investigate the simultaneous use of the altimeter as a passive radiometer operating at a different frequency band or between radar returns. (To measure relative change in emissivity of target areas.)

- Search and Rescue Aids — Objective: To determine via in situ measurements the utility, limitations, and accuracy of detecting, identifying, and positioning earth-located passive targets on vehicles in emergency situations using an orbiting side-looking radar system for detection and location.

- Multipath Measurements — Objective: To measure the statistical properties of signals simultaneously received over multiple propagation paths between shuttle-type vehicles and relay satellites; to determine the utility of an analytical multipath model for predicting signal fading.

- Imaging Radar — Objective: To determine the utility, accuracy, and limitations of an imaging radar in low-earth orbit.

- RF Noise — Objective: To measure the electromagnetic interference (EMI) at orbital altitudes in the frequency spectrum of 400 MHz to 15 GHz.

Earth Observations

- Lidar Measurements of Cirrus Clouds and Lower Stratospheric Aerosols — Objective: To measure the spatial distribution of cirrus clouds and lower stratospheric aerosols. A satellite-borne laser radar (lidar) will be developed for these measurements.

- Tunable Lasers for High Resolution Studies of Atmospheric Constituents and Pollutants — Objective: To develop a flight-qualified tunable injection laser monochrometer (TILM) system for remote sensing of the earth's atmospheric constituents and pollutants and for in situ measurements of atmospheric constituents and pollutants near the spacecraft.

- Multispectral Scanner for Coastal Zone Oceanography — Objective: To obtain narrow-band spectral signatures of coastal zone features from a spacecraft as a function of spatial resolution and field of view.

Environmental Physics

- Spacecraft Wake Dynamics — Objective: The primary objective is to determine the parameters governing the flow around ionospheric satellites or space stations. Of particular interest are the spacial extent and properties of the wake region of the spacecraft. The wake of a large body is created primarily by the body sweeping out ions from the ambient plasma and thereby causing large disturbances in the local ion and electron densities. In the interpretations of the measurements of geophysical properties made with satellite-borne instrumentation, it is important to determine the effects of satellite-caused perturbations.

- Barium Plasma Cloud Release on Sunward Side of the Earth — Objective: To monitor the natural magnetospheric plasma convection patterns on the sunward side of the earth.

- Optical Properties of Aerosols — Objective: To obtain a detailed knowledge of the interrelationship between the size, shape, concentration, and composition of aerosols and their optical properties under various meteorological conditions.

- Mapping of Upper Atmospheric Neutral Gas Parameters — Objective: To measure on a global scale the neutral number density of each constituent of the upper atmosphere and the temperature of the upper atmosphere as a function of latitude, longitude, height, and time using molecular beam techniques.

- Spacecraft Radiation Environment — Objective: The internal radiation environment of the ATL will be characterized in terms of radiation type, energy, intensity, and direction. This information will be processed in real-time to provide an accurate description of the radiation dose received by the crews. All data will be retained for detailed postflight analysis.

- Ultraviolet Meteor Spectroscopy from Near Earth Orbit — Objective: To obtain quantitative spectra of meteors in wavelength region below 3100Å (the atmospheric ozone cutoff).

Microbiology

- Colony Growth in Zero Gravity — Objective: To investigate the pattern of growth of bacteria colonies in near zero gravity.

- Interpersonal Transfer of Micro-organisms in Zero Gravity — Objective: To investigate the interpersonal transfer of micro-organisms between crewmen in weightlessness.

- Electrical Field Opacity in Biological Cells — Objective: To define the electrical field opacity error involved in measuring cell volumes using ground-based electronic techniques.

- Electrical Characteristics of Cells — Objectives: (1) To measure the electrophoretic mobility, surface zeta-potential, and surface-charge density of selected mammalian cell lines over the life cycles of the cells under weightless conditions; (2) To investigate electrophoretic methods which take advantage of a weightless environment to determine the electrical characteristics of cells.

- Special Properties of Biological Cells — Objective: Utilize weightlessness to perform a series of advanced studies to determine physical properties of mammalian cells.

Engineering and Operations

- Water Electrolysis in Zero Gravity — Objective: To evaluate the performance of water electrolysis cells (oxygen producing) in zero gravity.

- Carbon Deposition and Transport in Zero Gravity — Objective: To determine how carbon forms on a reduction or disproportionation catalyst in zero gravity and how the carbon can be periodically removed from the catalyst and transported by a continuous or intermittent recycle gas flow to a collection device.

- Steam Generator — Objective: To obtain steam generator performance data while the generator is operating at reduced gravity levels in earth orbit.

Environmental Effects

- Sampling of Airborne Particles and Micro-organisms in Space Cabin Environment — Objective: Postflight analysis of experimental data obtained during a manned earth orbital mission is expected to provide the following results: (1) The types of micro-organisms present in the cabin air environment; (2) Quantification of these micro-organism types; (3) The rate of change of these micro-organism types with respect to operations of, and in, the spacecraft; (4) The types, quantity and rates of change of non-viable particles; (5) The origin of the non-viable particles (in some cases); (6) Classification of both viable and non-viable particles as to size.

- Orbital Fatigue Experiment — Objectives: To obtain in situ data on the effects of the space environment on: (1) Material fatigue life characteristics; (2) Fatigue crack propagation.

- Environmental Effects on Nonmetallic Materials — Objective: To collect in situ data on the effects of the near-earth space environment on elastomers, coatings and polymeric films.

- Fluids in Zero Gravity — Objective: To validate a set of analytical models which attempt to describe and predict the behavior of fluids in a reduced gravity environment.

REQUIRED SORTIE MISSIONS

The individual experiments listed above have been defined in sufficient depth to permit their grouping into selected payloads. Fully recognizing the capabilities of the shuttle and sortie laboratory (through close coordination with MSC and MSFC personnel), it has been determined that three 7-day Shuttle Sortie missions could fly all of these 30 experiments one time. One of these three mission payloads (consisting of 13 experiments) has been selected as a typical design mission for which the "requirements on the Shuttle" are listed in Appendix A. Just as advanced technology research and development efforts are multidiscipline in nature, these three mission payloads are necessarily multidiscipline in composition in order to maximize utilization of the capabilities provided by the Sortie Laboratory's pressurized module and unpressurized pallet.

PROPOSED TOTAL FLIGHT SCHEDULE

It appears that LRC researchers will provide sufficient experimental payloads to utilize two 7-day Shuttle Sortie missions each year commencing in 1980. This forecast is based upon the following:

- The presently-identified P.I.'s want to fly their experiments many times for statistical purposes and to modify experimental equipment and/or procedures.
- The number of involved researchers and experiments will noticeably increase when it becomes a reality that the researcher truly has routine access to space.

LASER COMMUNICATIONS

The Marshall Space Flight Center is evaluating laser communications for consideration as part of a world-wide communications system. Shuttle Sortie missions can aid in the development of those links involving low earth orbit systems by utilizing existing ATS-G ground stations. These experiments will be used to generate scientific and engineering data parameterizing these links in order to evaluate designs for future operational system consideration. This research will provide the necessary technology evaluation for use in developing a world-wide extremely high bandwidth communications network, probably a hybrid microwave/laser system including deep space capability.

DISCIPLINE AREA - LASER COMMUNICATIONS

GOALS AND OBJECTIVES FOR THE 1980'S

The development of laser/optical communications for a variety of eventual space uses has been identified as a specific program objective of NASA. Laser communications will eventually be used for deep space communications, for synchronous data relay staellites, and for low-earth-orbit satellites. Low-earth-orbit satellites may communicate continuously with a system of synchronous data relay satellites which then relay the information to ground, or they may dump information at very high rates directly to ground stations on each pass overhead.

Communication satellites for both civilian and military purposes are already a reality. A huge expansion of communications capacity via satellites for both military and civilian purposes is expected during the next 20 years. Data-relay-satellite

systems and low-earth-orbit systems to synchronous systems will eventually use lasers almost exclusively. Depending on the applications and requirements, microwave or hybrid microwave/laser systems may be used from synchronous orbit to ground and low earth orbit to ground. Developments now taking place will help define the efficacy of direct communications between spacecraft and ground via laser systems and will help to define the circumstances directing use of lasers. These experiments will also help to define whether deep space systems should communicate directly to ground or through a data-relay-satellite system.

In summary, the goals and objectives of the laser communications are to aid in the huge expansion of world wide communications capability which is expected to take place during the next 20 years, including communications for deep space purposes.

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

The sortie mode can contribute to the development of three modes of laser communications:

- Communications between low-earth-orbit systems and synchronous altitude systems.
- Communications between two or more low-earth-orbit systems.
- Direct communications between low-earth-orbit systems and ground.

In particular, the sortie mode, by flying experimental low-earth-orbit laser communication systems in the shuttle, can contribute to these developments by A) communicating with synchronous laser communication systems such as the ATS-G visible laser communication experiment (VLCE), B) communicating with existing laser communications ground stations such as the ATS-G ground station, and C) communicating with low-earth-orbit satellites, possibly deployed by the shuttle itself. The purpose of the flights will be to demonstrate the laser communications systems and to make scientific and engineering evaluations of the link parameters and system characteristics.

Eventual operational systems will require bandwidths from the hundreds of megabits to several gigabits. Early experimental systems such as might be flown on the shuttle sortie missions can demonstrate most of the capabilities and evaluate most of the link parameters and system characteristics with lower bandwidths, such as thirty megabits to two hundred megabits. The present ATS-G VLCE has a thirty megabit link.

REQUIRED SORTIE MISSIONS

- Low-earth-orbit to synchronous-satellite-laser communication experiment
- Low-earth-orbit to ground laser communication experiment
- Low-earth-orbit to low-earth-orbit-laser communication experiment.

SORTIE MISSIONS OUTLINED IN APPENDIX B.

PROPOSED TOTAL FLIGHT SCHEDULE

The state-of-the-art of laser communications is such that a series of experimental systems could be flown on the earliest shuttle sortie missions. In particular, the ATS-G VLCE ground station will exist and be available for updating in time for the earliest flights to conduct low earth orbit to ground station experiments. The ATS-G VLCE satellite itself is expected to be launched in 1975 and have a lifetime of two years; hence it is expected to be dead. To conduct the low-earth-orbit to synchronous orbit experiments, a second ATS-G VLCE type satellite will need to be launched. Possibly the prototype of the ATS-G payload can be refurbished for this purpose. A similar package could be flown to orbit by the shuttle and be released in low earth orbit to demonstrate the low-earth-orbit to low-earth-orbit link by communicating with the shuttle.

For purposes of this document a minimum of three flights is proposed, one each year for the first three years of shuttle sortie mode availability, with a separate ATS-G type synchronous payload launched in 1980 to communicate with a shuttle sortie or sortie payload also launched in 1980.

- 1979 — Shuttle sortie mission to demonstrate and evaluate low earth orbit to ground laser communications
- 1980 — Synchronous satellite launch plus a shuttle sortie mission to demonstrate and evaluate the low earth orbit to synchronous orbit laser communications
- 1981 — Low-earth-orbit satellite launched via shuttle to communicate with second package on shuttle.

By the end of this series the capabilities and requirements of laser communications will be defined to the point that operational systems may be developed. It is entirely possible that at this point laser communications can be used to expand and update the communications capability of the shuttle itself.

EXTERNAL CONTAMINATION

In order to ensure an acceptable environment for Shuttle Sortie experiments, the Marshall Space Flight Center (MSFC) is studying methods to eliminate or alleviate external contamination problems. These methods include (1) minimizing the initial release of contaminants by basic design practices, (2) reducing contamination inherent in manufacture, test, deployment and operation of payloads, (3) controlling operational events which contribute contaminants, (4) characterizing the shuttle-induced environment and determining the effects on optical and other critical spacecraft and experimental surfaces, and (5) providing techniques for removing contaminant deposition in situ.

DISCIPLINE AREA - EXTERNAL CONTAMINATION

GOALS AND OBJECTIVES FOR THE 1980'S

The goal of this discipline area is to ensure a contamination-free environment for the entire shuttle cluster. The objectives listed below are designed to achieve this single goal. This discipline area does not include biological, manufacturing, or interior-cabin atmosphere except in the respect that they could cause a degradation in performance of optical systems. The overall objectives in the area of external contamination are:

- Minimize, by basic design of the Shuttle Sortie Lab and shuttle payloads, the amount and types of contaminants which may be released to the environment of the shuttle
- Manufacture, test, launch and deploy the payloads and the other modules with the view toward reducing contamination
- Control on-board operational events of the various modules to preclude or reduce the potential for contamination
- Monitor the environment of the shuttle cargo bay in the vicinity of contamination-sensitive systems or surfaces to provide data needed to make operational decisions to close aperture doors, for example, or to make corrections in observational data
- Provide techniques and devices to further define the dynamic characteristics of the induced environment of the shuttle
- Provide techniques and devices which will remove contaminant material from the critical surfaces of external systems in situ.

B

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

It is assumed that various optical experiments, diverse monitors using optics, and critical thermal control surfaces are being proposed by other discipline areas for utilization of the sortie mode. Many of these systems can become seriously degraded by such things as RCS engine firings, waste dumps, experiment venting, and the outgassing of the nonmetallic materials used in any of the modules. Realistically, there will be degrading contamination present in the vicinity of the optical systems. Therefore, monitoring and abatement devices must be provided for the shuttle sortie mode optical experiments and other sensitive experiments or systems.

REQUIRED SORTIE MISSIONS

- Contamination-related equipment is required on each sortie mission which contains experiments or any other system whose performance could become degraded if exposed to an induced atmosphere.
- This equipment or modified versions of it, should be included on those sortie missions which are known to produce significant amounts of contaminants in the form of particulates or vacuum condensable material (VCM).

SORTIE MISSIONS, OUTLINED IN APPENDICES

- All optical astronomy payload missions
- All Manufacturing-in-Space missions
- All missions containing critical optical, thermal, or other surfaces.

PROPOSED TOTAL FLIGHT SCHEDULE

- 1979 — All mission flights
- 1980 — All mission flights
- 1981 — All mission flights
- 1982 - 1990 — All optical payload missions or missions whose payloads may be sensitive to the effects of contamination

DEVELOPMENT OF LOW-COST PAYLOAD TECHNOLOGY

Because the NASA cost improvement program embraces all discipline areas and overall spacecraft, users' payload costs must be reduced significantly in order to fly cost effective shuttle sortie payloads. The Goddard Space Flight Center (GSFC) is developing a prototype low-cost payload spacecraft which can be used to evaluate the shuttle's capability for (1) launching, resupplying and refurbishing free-flying applications and scientific spacecraft payloads, and (2) retrieving malfunctioning payloads in emergencies.

DISCIPLINE AREA

Development of Low Cost Payload Technology - The NASA cost improvement program cuts across all discipline areas, but of immediate and specific importance is the necessity to arrive at new payload design approaches which maximize the lower cost potentials of future payloads through the use of shuttle launch, retrieval, and resupply capabilities.

GOALS AND OBJECTIVES FOR THE 1980'S

It is vital for NASA to reduce overall spacecraft and users' payload costs significantly in order to be able to afford a sufficient number of payloads for the shuttle in the era of the 80's.

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

The sortie mode of the shuttle can play three major roles in achieving lower program discipline costs. These are as follows:

- As a development tool for the launch, checkout and demonstration proof flight of initial prototype low cost spacecraft(s).
- By providing resupply of orbiting free-flying spacecraft systems to extend the life of the subsystems, update instruments, and in general, increase the scientific return for the initial program development investment.
- By providing emergency retrieval capability for seriously malfunctioning spacecraft (where cost effective), thereby increasing the "forgiveness" of the systems and reducing the requirements for the extremely expensive multiple component redundancies and the degree of single point failure modes.

REQUIRED SORTIE MISSIONS

- Low cost payload demonstration experiment.
- Launch, resupply and refurbishment of free-flying applications and scientific spacecraft payloads.
- Emergency retrieval of seriously malfunctioning or degraded payloads.

SORTIE MISSIONS OUTLINED IN APPENDIX D

PROPOSED TOTAL FLIGHT SCHEDULE

In order to demonstrate and prove out the concepts for low-cost payloads design utilizing shuttle sortie capabilities, it is extremely vital that the earliest possible launch date be established for the proof demonstration flight of a typical low-cost payload. The viability of the shuttle's cost improvement potential rests on an early demonstration of its ability to launch, rendezvous, dock and resupply a low-cost payload. Subsequent flights would be required to update and/or retrieve similar operational payloads.

ZERO GRAVITY OPTICAL TEST FACILITY

Goddard Space Flight Center (GSFC) is designing a shuttle-borne test facility which would be used to develop optical technology for future earth resources and optical astronomy missions. This in-space test bed would checkout advanced optical systems, high resolution optical instrumentation, and low-temperature optical active and passive cooling systems. It would provide a cost effective means of short cutting the lengthy development cycle for precision optical systems through the use of short duration (sortie mode) prototype and pre-operational calibration flights.

DISCIPLINE AREA

Zero gravity optical test facility (Optical Technology Development for Earth Resources and Optical Astronomy Mission of the future).

GOALS AND OBJECTIVES FOR THE 1980'S

Both Earth Observation and Optical Astronomy Missions of the 1980 era will require orders of magnitude improvement in the optical system performance. Such future missions as EOS, SEOS, LST and IR Astronomy will not only require a substantial scale up in mirror diameters and optical figure requirements, but will also require substantial optical system alignment and cooling performance improvements. As a cost effective means of validating the performance of such optical systems in the zero gravity space environment, an optical system checkout facility to be used in the shuttle sortie mode is proposed.

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

The most important functions of this general purpose optical system test facility will be the detection and evaluation of the performance of overall advanced optical systems specifically to include assessment of dimensional changes on mirror surfaces and systems in optical trains, the evaluation of thermal gradients, the performance of Cryogenic cooling systems, and the effects of structural/thermal distortions on optical instrument systems.

The most significant contribution of such a sortie mode facility is cost improvement. Whereas at present there is no truly effective way of assessing performance of these optical systems in a 1G environment, other than by indirect and extremely expensive analysis and test, this facility offers the capability of building relatively inexpensive prototype systems (without much of the present management success constraints) and checking out such systems in the actual operational environment for a short period of time. The optical system would then be returned to earth for final evaluation and modification prior to its operational use.

REQUIRED SORTIE MISSIONS

One of the major aspects in developing precision optical systems, ultra-lightweight mirrors, and/or large diameter optics is the problem associated with development, manufacturing, and calibration cycles of these systems in 1G environment for ultimate operation in space. As an example, because of significant mirror material anelasticity as shown in various independent studies by Battelle Memorial Institute, the Boeing Company and Perkin Elmer Corporation, it is impossible to devise meaningful ground tests to evaluate zero G performance. Other than by analytical prediction, and rather indirect testing, there is no way to verify or measure the figure change of these mirrors as a result of internal and external stress relaxation in the gravity released condition. On the other

hand, through the use of the shuttle sortie mode, it is possible to conduct a mirror figure test in orbit. Such a zero G test would establish the vitally-needed correlation between analytical mirror figure predictions, ground test data, and actual in-orbit diffraction-limited figure measurements. Typical future programs requiring extremely lightweight high resolution optical elements are SEOS, EOS, and LST. Typical programs requiring instrument systems checkout and calibration are IR missions with low-temperature coolers, EOS instruments, and SEOS instrumentation.

SORTIE MISSIONS OUTLINED IN APPENDIX

Zero "G" Test Facility Operations: In any particular flight, once in orbit the shuttle cargo bay doors will be opened, the Zero G facility will be rotated to the vertical position, and the light shield will be fully elevated. Thermal and strain sensing instrumentation will be activated. The figure sensor will be activated and both instantaneous photos of mirror figure fringes as well as videcon scanning of the mirror figure will take place. Each videcon scan made of the figure will last no longer than 10 minutes. At least eight such scans and accompanying photo shots are desirable. Before and after each event, shuttle activities can proceed normally. During the 8 10 minute events, a quiet environment (no thruster firings or high disturbance torques) is required.

The payload specialist will have the responsibility for the deployment of the facility from its storage position within the cargo bay to its fully extended vertical position. In addition he will have the responsibility for electrical activation of the facility and the initiation of the data-taking events.

During the first mission the specialist will monitor and maintain internal alignment of optical elements and sensors. Through the selected use of the figure sensors and temperature and strain instrumentation, he will monitor the effects of transient cooling on the optics and the facility. He will monitor the Videcon data of the mirror figure as well as controlling specific mirror temperature levels through the operation of adjustable heaters.

For subsequent flights which would be longer in duration, he may be required to make periodic alignment adjustments of the figure sensor system as well as adjustments in sensitivity based on videcon display data within the shuttle cabin.

PROPOSED TOTAL FLIGHT SCHEDULE

The flight schedule for this optical test bed must be closely keyed to the development schedules of the applications and space sciences programs which desire

Figure 1-2. Zero G Optics Tests Facility

to make use of the facility. The following only represents a best guess type schedule:

- 1980 — Two launches for EOS sensors and optical instrumentation
- 1981 — One launch for LST figure checkout
- 1982 — Two launches for advanced EOS, SEOS and IR astronomy missions

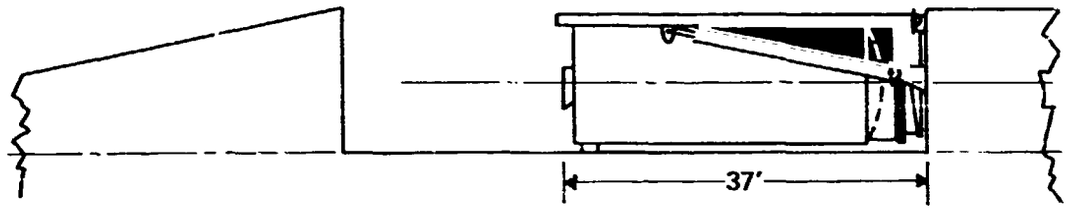

Figure 1-3. Zero-G-Mirror Launch Configuration

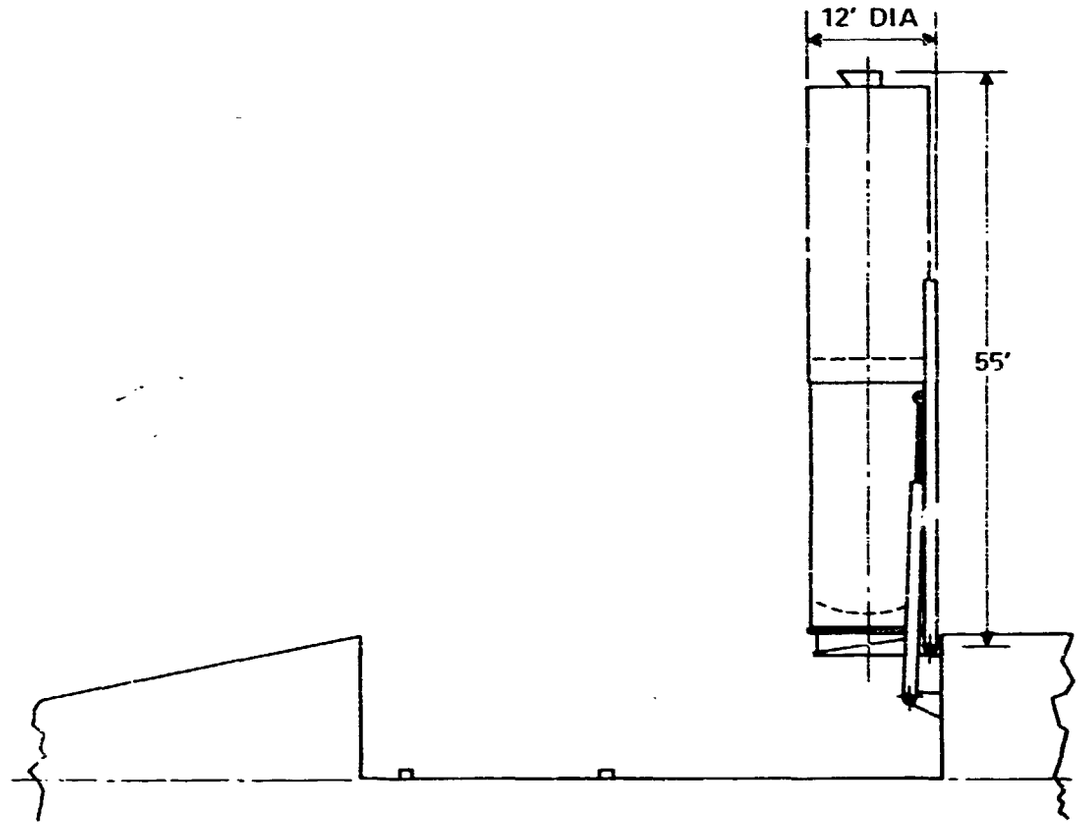

Figure 1-4. Zero-G-Mirror Figure Test Configuration

SPACE SHUTTLE FREE-FLYING EXPOSURE MODULE

A candidate payload for the first space shuttle development flight is a free-flying exposure module called the Long Duration Exposure Facility. The payload will carry low-cost, noncritical experiments which are quite flexible in their requirements such that they will place no constraints on space shuttle's operation. The payload's experiments will be essentially passive and will make maximum use of space shuttle's unique capability to launch and later retrieve for ground-based studies a large, heavy experiment payload.

In the performance of advanced studies to identify experiments for the Long Duration Exposure Facility, many experiments were uncovered which can be performed on a free-flying module which space shuttle delivers and later retrieves. It is therefore felt that a number of missions should be planned for delivery and retrieval of such an exposure module. Experiments identified which can be performed on these missions include the areas of meteoroid technology and science, microbiology and macrobiology, and material technology and science. The first Exposure Module will stress the first area and carry examples from the latter two areas. Later exposure modules will be concerned principally with the latter two areas. The following pages contain particular experiments from these areas along with their justification.

METEOROID EXPERIMENTS

The use of a large-area free-flying module make possible a clear definition of the meteoroid environment. Not only can the meteoroid hazard to large, long-duration spacecraft be defined but also, interesting new fields connected with the hazard to spacecraft from man-made debris and the impact of extra-terrestrial material on the upper atmosphere particulate airburden can be studied. Recovery of the module enables many scientific experiments which heretofore have been impossible to be conducted on meteoroids. In fact, many of the experiments listed in this section are such that they are both of a technological and scientific nature.

DISCIPLINE AREA

Particulate matter in space (meteoroids, cosmic dust and man-made debris)

GOALS AND OBJECTIVES FOR THE 1980'S

To perform both scientific and technological investigations of particulate matter in space. Specifically the objective of these investigations will be to better define the population mass relationship — the composition and structure, the origin, and the probability for and effects of collisions between these particles and spacecraft.

A thorough understanding of meteoroids and cosmic dust in space is essential before man can develop a sound understanding of the origin and evolution of our solar system. Therefore, these investigations of particulate matter in space support a basic scientific goal of NASA.

An understanding of the particulate environment of space and the probability for and the effects of collisions between these particles and spacecraft is necessary to design low-cost effective meteoroid protection systems for the large long-life spacecraft such as research modules, tugs, and space stations planned for the late 1980's and the 1990's.

Investigations of man-made debris are a critical part of these particulate matter studies. The time is rapidly approaching, if it has not already arrived, when man-made debris in space will be more critical to future space operations than the natural meteoroids of celestial origin. For example, recent spacecraft explosions in near-earth orbit, some of which were accidental and some of which, particularly several Russian spacecraft explosions, were probably planned, resulted in increases of many orders of magnitude in the number of large particles having sufficient mass to result in critical-impact damage to near-earth spacecraft. In many cases these man-made debris particles will remain in space posing a threat to spacecraft for many years. Debris also accumulates in space from routine operations such as spacecraft dumps and shroud and adapter separations.

A second new and interesting area which is of particular concern to environmentalists is the impact of airborne particulates on the weather. The portion of the particulate airburden due to extra-terrestrial material forms a natural benchmark against which man's contribution may be measured. Already the importance of volcanic activity is recognized as influencing the particulate airburden; large area meteoroid counting experiments can be expected to prove or disprove the importance of the extra-terrestrial activity.

SORTIE MODE CONTRIBUTIONS TO PARTICULATE MATTER STUDIES - EXPOSURE MODULE EXPERIMENTS

Sortie missions to deliver into space and later sortie missions to retrieve from space large, simple, very inexpensive and, in some cases, near-passive Exposure Modules will reveal more about the near-earth meteoroid environment in the mass range between 10^{-15} and 10^{-5} grams than the combined knowledge obtained from all previous meteoroid flight experiments. The module can be relatively simple, as shown in Figure 1-5.

The module will perform a number of experiments to obtain needed data on the meteoroid environment in space and the effects of the meteoroid environment on spacecraft.

Environment Definition Experiments - The present best estimate of the near-earth meteoroid environment is the model presented in the NASA space vehicle

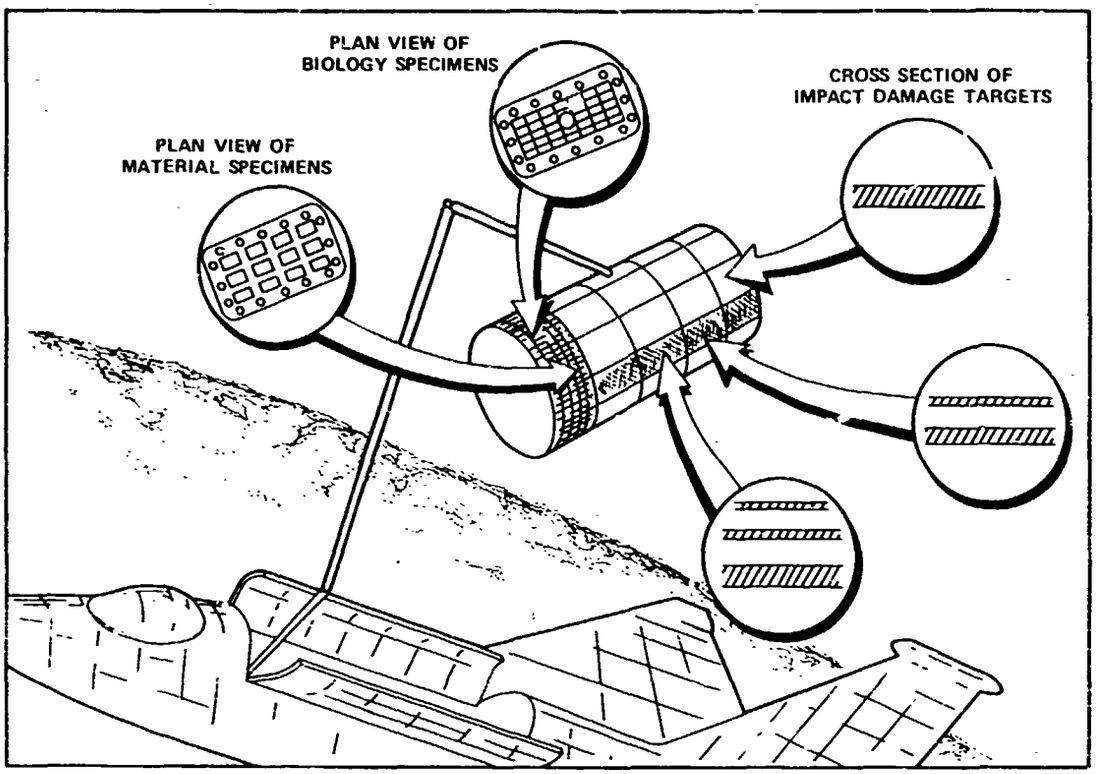

Figure 1-5. Long Duration Exposure Facility

design criteria document NASA SP-80B. The curve of the meteoroid impact flux as a function of meteoroid mass which is predicted by this model is shown in Figure 1-6. This curve is based essentially on three sets of experimental data - the Explorer pressure cell penetration data, the Pegasus capacitor discharge penetration data, and photographic meteor data. None of this data contains direct measurements of meteoroid mass as a function of impact flux.

The Explorer data consists of measurements of meteoroid penetration rates in 1- and 2-mil thick steel plates. A penetration here is defined as an impact which rendered the plate incapable of maintaining a pressure differential. The Pegasus data consists of measurements of meteoroid penetration rates in 8- and 16-mil thick aluminum plates. However, in the Pegasus data, a penetration is defined as an impact which caused a charged capacitor bonded to the rear of the plate to discharge below the threshold level which was required for detection.

The meteor data represents a third and even more different set of measurements taken from the photographic plates of observed meteors - namely measurements of luminosity, velocity, and counts of meteors in the earth's atmosphere. There is a great deal of uncertainty in the estimated mass or penetrating capability of the meteoroid responsible for any observed meteor.

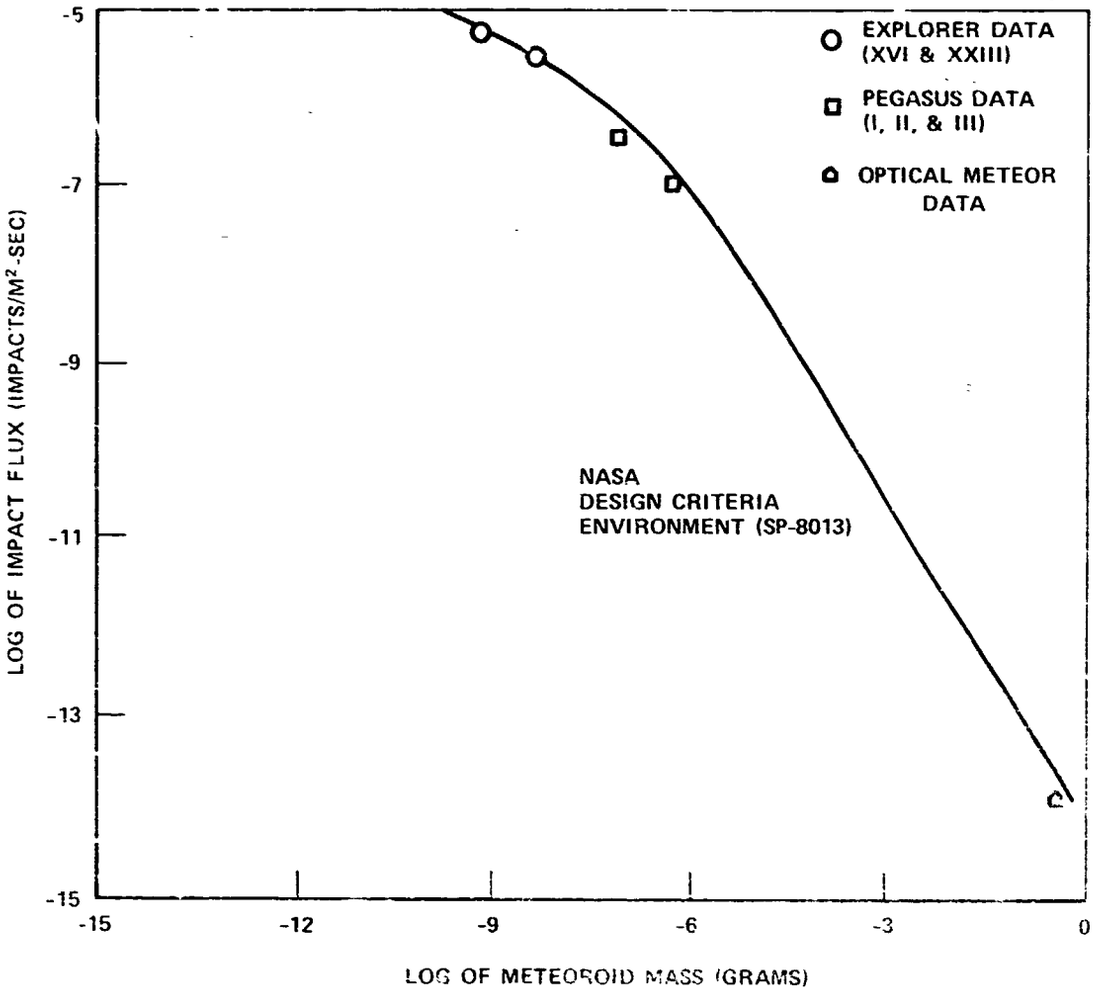

Figure 1-6. Current Best Estimate of Near Earth Meteoroid Environment

The Explorer, Pegasus, and photographic meteor data also represent measurements made in widely separated meteoroid mass ranges. Because of the fact that different detectors were used, different quantities were measured, and the measurements were made in widely separated ranges it is difficult to relate the Explorer, Pegasus, and photographic meteor data. It is even more difficult to establish the true meteoroid mass flux environment with the data.

No meaningful uncertainty limits can presently be placed on the estimated meteoroid mass flux environment.

The launch and later the recovery of a simple exposure module will allow identical measurements to be made over a meteoroid mass range of approximately 10 orders of magnitude as is indicated on Figure 1-7. The measurements can start

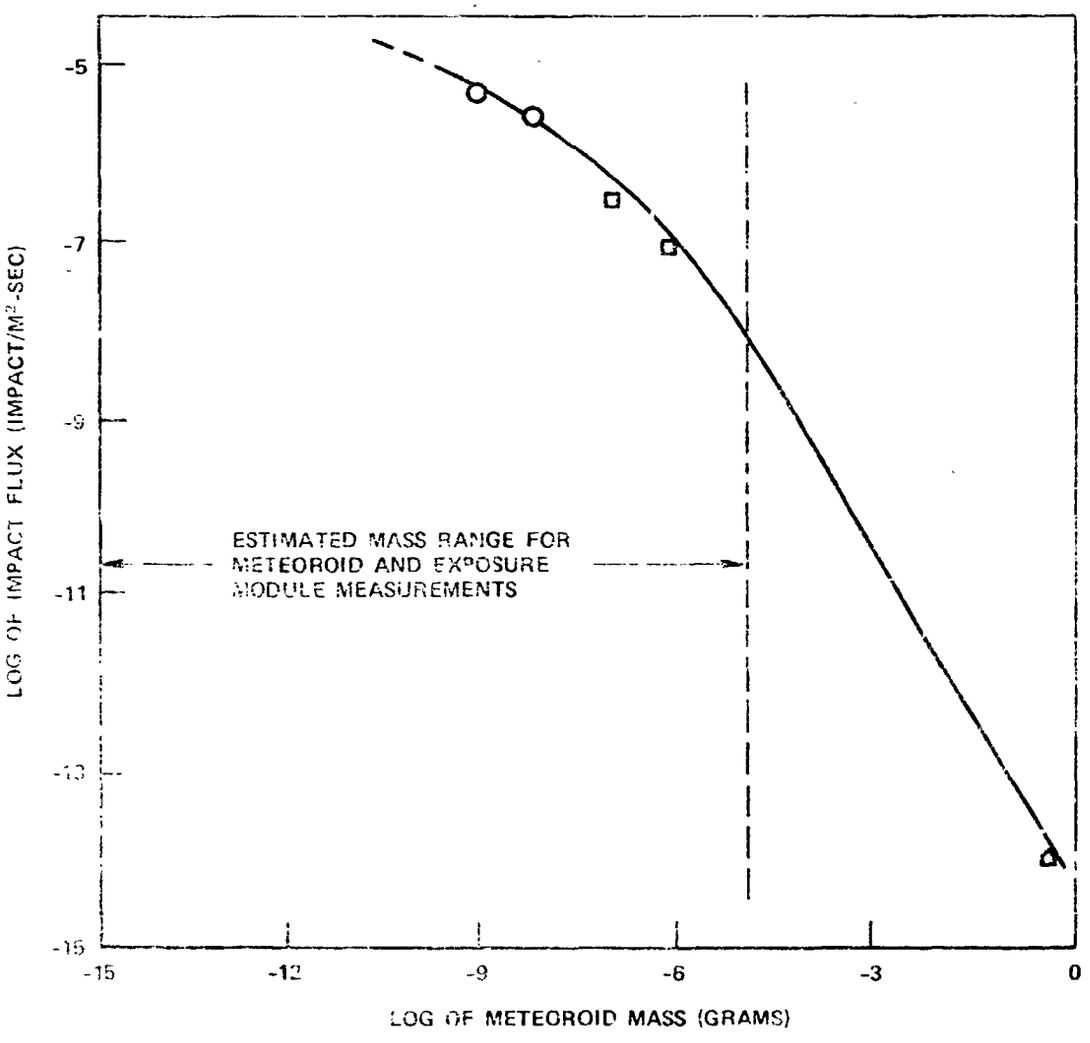

Figure 1-7. Estimated Mass Range for Meteoroid and Exposure Module Measurements

with meteoroids having masses approximately 5 orders of magnitude below those detected by the Explorer satellites and extend to meteoroids having masses several orders of magnitude greater than those detected by the Pegasus satellites. Such a set of consistent measurements will allow greatly-improved environment models to be constructed.

In addition to permitting consistent measurements to be made over a large mass range, the recoverable feature of the meteoroid and exposure module will permit more definitive measurements than have been possible on previous meteoroid satellites. For example, the exact penetration capability of each impacting meteoroid can be measured with the module. The Explorer and Pegasus

satellites could only measure the total number of impacts which resulted in penetration depths greater than some threshold level. More importantly, the module will allow detailed laboratory examinations of each meteoroid crater or peretration. Such laboratory examinations can reveal important clues to better estimate the mass of the impacted meteoroid, its density, structure, composition, and other characteristics and effects.

Meteoroid Detector Experiments - The complete spectrum of meteoroid impacts which are expected in space cannot be simulated in the laboratory for two reasons. First, insufficient knowledge exists to physically describe meteoroids. Second, the available laboratory particle accelerators are limited to velocities which are considerably less than the average meteoroid velocity in space. The response of meteoroid detectors to the complete spectrum of expected meteoroid impacts therefore cannot be studied in the laboratory. This fact introduces many uncertainties in the analysis of the data from these detectors. Some of these uncertainties can be eliminated by exposing the instrument in space and later returning it to the laboratory for study. In this manner, the instrument response signals recorded during the exposure in space can be compared later with the craters or penetration observed in postflight laboratory examinations of the instrument.

Meteoroid Damage Experiments - Spacecraft designers must not only know the meteoroid environment - they must know the damage the environment will inflict on spacecraft. The exposure module will permit experiments to directly determine the types of damage than can result from meteoroid impacts. For example, the examination of witness plates, which will be located behind thin skins on the module while in space, can establish the pattern and damage capability of the spray that is ejected when spacecraft skins are penetrated or spalled. Examination of penetrated multi-sheet panels can establish if the damage is confined to a small region around the impact or if blast loading produces large cracks which propagate away from the impacted area, thus substantially degrading the integrity of the panel. This type of information is critical to establish a tolerable level for meteoroid damage.

Sortie Can Experiments - Active experiments to observe and study meteors from space can be performed with cameras and spectroscopes mounted on the sortie's can. Such experiments can contribute to a better understanding of larger mass meteoroids (greater than 10^{-5} grams). Specifically quantitative spectroscopy of meteor radiation provides us with a powerful method of determining elemental abundances in meteoroids. Current ground-based techniques provide meteor spectra in the 3100Å to 9000Å wavelength region. Observations of meteors from above the atmospheric ozone region would extend the wavelength region below the 3100Å ozone cutoff to near 2000Å. This region, from 2000Å to 3100Å is extremely important in that a number of elements suspected to be present in meteoroids

radiate strongly there. Some of the spectral lines that are important in meteor spectroscopy are shown in Figure 1-8.

Quantitative spectroscopy is now available and being analyzed to meteor radiation in the wavelength region 3100Å to 9000Å. These data are being used to measure the elemental abundances and their distribution in different kinds of meteoroids.

Carbon is of major interest in the origin and evolution of the solar system, and is suspected to be present in most cometary meteoroids and hence in most meteoroids. If carbon is not present, it indicates that the meteoroid is not of cometary origin. Absence of carbon also indicates a much stronger material. Carbon cannot be detected in the presently accessible wavelength region, but has a strong line at 2478Å. Silicon is of major interest in meteoroids because, combined with oxygen, it is believed to make up most of the mass of most meteoroids. Silicon is almost never seen in present meteor spectra because the weak 3905Å line is masked by stronger iron lines. A strong silicon line exists at 2881Å.

Magnesium is the most abundant metal found in most stony meteorites. Although magnesium has two strong triplets in the presently accessible wavelength region (multiplet 3 at 3835Å and multiplet 2 at 5180Å), both of these multiplets are above

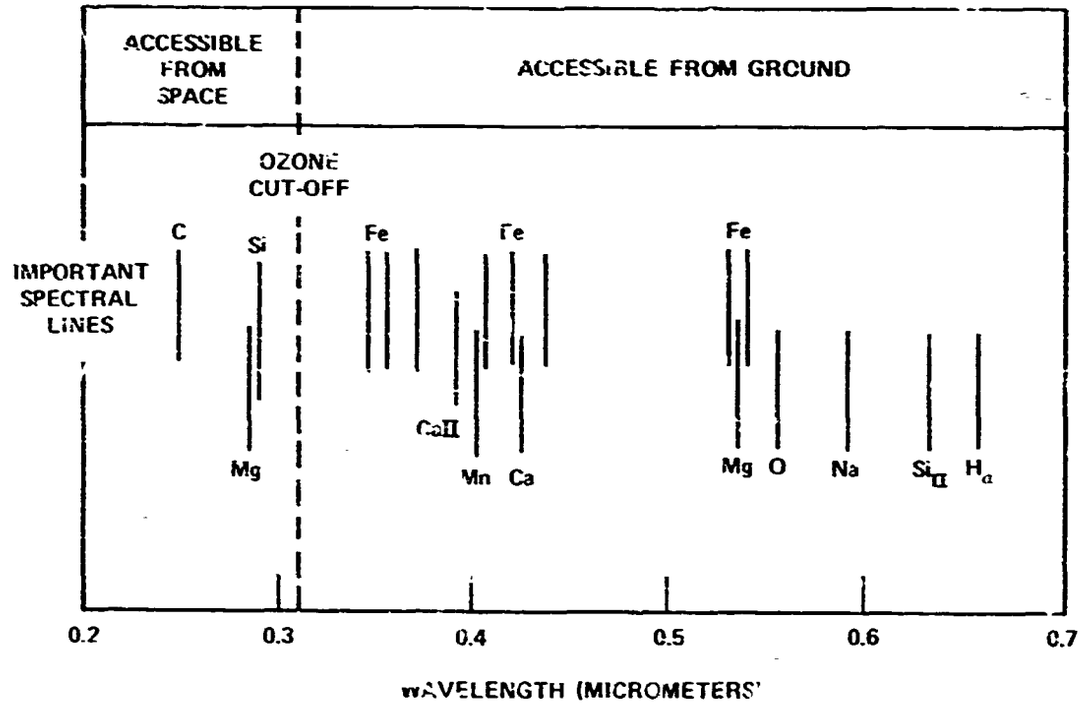

Figure 1-8. Some Spectral Lines that are Important in Meteor Spectroscopy

metasuable states of magnesium which introduces a large uncertainty in magnesium abundance determinations. Use of the strong, ground-state magnesium line at 2852Å would circumvent this problem. Measurements of the 2802Å ionized magnesium line would aid significantly in the study of meteor ionization. Two strong iron lines at 2533Å and 2719Å would serve as convenient calibration lines.

Measurements of these lines must be made from above the earth's ozone layer (50-60 kilometers altitude). It is now within the state-of-the-art to make an automatic meteor-sensing-and-triggering, middle-ultraviolet, widefield spectrograph of high-spectral sensitivity to obtain the required spectra. Such spectrographs mounted on sortie cans can obtain the desired data while viewing the dark side of the earth's atmosphere.

Most meteoroids are believed to be extremely fragile. They are observed to break-up when entering the earth's atmosphere as dynamic pressures of only a small fraction of an atmosphere. Such particles can probably never be trapped or captured without damage. High speed photographic systems can be operated from sortie cans to obtain detailed pictures of meteoroids which will be of tremendous value in observing the structure and thus in turn provide many clues as to the origin and evolution of the meteoroid.

Man-made debris can be routinely monitored using optical systems on sortie missions. The optical systems to be used will provide data on the orbit and size of the debris. Such systems will also provide data on orbits of natural meteoroids.

TITLE OF SORTIE MISSIONS REQUIRED

- Long Duration Exposure Facility
- Ultraviolet Meteor Spectroscopy from Near Earth Orbit (1 experiment possibly on sortie can)
- Meteoroid Photography (1 experiment possibly on sortie can)
- Man-Made Debris Monitoring (1 experiment possibly on sortie can)

TITLE OF MISSIONS FOR WHICH REQUIREMENTS & CHARACTERISTICS ARE ATTACHED

- Long Duration Exposure Facility

PROPOSED FLIGHT SCHEDULE

- 1979 – Meteoroid and Exposure Module
- 1981 – Exposure Module
- 1984 – Exposure Module

MICROBIOLOGY AND MACROBIOLOGY EXPERIMENT

One category of experiments which is scientifically valuable for space research and which would provide basic data for technological and life sciences applications is related to the effects of the space environment on fundamental biological and macro biological processes. Past and present biological experiments, including those of Biosatellite, Gemini, and Apollo have been, or will be, limited to at most a few weeks of exposure, with several weight and volume constraints and limited sample quantities. The free flying unpressurized recoverable concept offers a 6-to-9 month continuous exposure time for a wide range of biologicals to various combinations of zero g, vacuum, and radiation with the weight and volume constraints in the present day biological experiments. With the present day orbital experiments can expose on the order of 10[illegible] biological samples with ingenious packaging configurations, the space shuttle through the experiment module is able to offer biologists opportunities for exposing literally millions of biological samples.

The following contains a list of potential experiments that have been identified.

DISCIPLINE AREA

Microbiology (Exploratory Investigations)

GOALS AND OBJECTIVES FOR THE 1980'S

Perform a large number of basic exploratory microbiology experiments in a very inexpensive mode to obtain basic data on life forms in space and the effects of the space environment on these life forms and to generate basic data on biological related processes in space which may have future economical or social benefits.

CONTRIBUTION OF THE SORTIE MODE

Preliminary studies indicate that a large number of simple biology-related experiments are desirable and can be cheaply and efficiently performed in space on an exposure module which can be transported into space, left free-flying for periods of time, and returned to ground-based laboratories for observations and analysis.

Examples of such experiments are the following:

- Kinetics of Spore Germination — Objective: To evaluate a well-characterized model for assessing the effect of zero g on the function of enzymes.

- Kinetics of Enzyme Activity — Objective: To evaluate the kinetics of conversion of glucose to strach with an enzyme attached to an inert carrier under the influence of zero g.

- Insect Development and Differentiation — Objective: To evaluate the long-term effect (6 months) of zero g on the development and differentiation of Tribolium confusum, the flour beetle.

- Evaluation of New Life Detection Concept — Objective: To evaluate the performance of a life-detection method based on the electrical conductivity of microbial soil suspensions in the zero "g" environment.

- Detection of Life in Meteoroids — Objective: Self explanatory.

  Comment: Not feasible unless the internal heat caused by meteoroid impact can be dramatically reduced.

- Fermentation of Phenols by Actinomycetes — Objective: To demonstrate cellular growth and yield enhancement under zero g condition.

- Evaluation of Photoreactivation in the Space Environment — Objective: To measure the occurrence and extent of photoreactivation of Bacillus subtilis in the space environment.

- Nature and Frequencies of Genetic Mutations — Objective: To determine the frequencies of reversion of auxotrophic mutations in Bacillus subtilis and characterize the nature of the revertants under the space environment.

- Physical and Biological Characteristics of Microbial Aerosols — Objective: To determine the physical and biological decay processes and stability o microbial aerosols in the zero "g" condition.

- Adaptation of thermophilic and psychrophilic enzyme systems — Objective: To analyze the conformational structures of enzymes of thermophilic and psychrophilic cultures in the zero "g" environment.

- Analysis of Enzyme Kinetics — Objective: To evaluate the function of RNA-ase in solution in space environment.

- Motility of Micro-organisms, Chemotaxis and Phototaxis — Objective: To compare the chemotactic and phototactic behavior on the motility of micro-organisms in the zero "g" environment with ground controls.

- Differentiation and Development of the Sea Urchin — Objective: To compare the long-term effect of zero "g" on growth and development of the sea urchin.

- Differentiation and Growth of Plant Cellous Tissue — Objective: Same as above.

- Kinetics of Antibody Formation — Objective: To evaluate the rate and amount of antibody produced from single cells under the effect of zero "g".

- Characterization of Porphyrin Structure — Objective: To compare the rate of synthesis and conformational structure to porphyrins in the zero "g" environment.

- Kinetics of Lysosome Deterioration by Antigen-Antibody Complexes — Objective: To compare the rate of deterioration of lysosomal membranes by antigen-antibody systems under zero "g" conditions.

SORTIE MISSION TITLE - EXPOSURE MODULE (MICROBIOLOGY EXPOSURE EXPERIMENTS)

SAME AS ABOVE

SCHEDULE

- 1979
- 1981
- 1984

MATERIALS, COMPONENTS AND SYSTEM EXPOSURE EXPERIMENTS

The free-flying exposure module provides an ideal low-cost approach to testing and determining the effect ot the space and shuttle environment on materials, components and systems experiments. Many of these experiments are passive, requiring only ground-based analysis of the returned experiments. Some of the examples of experiments which follow do require power but not excessive amounts. With the low-cost aspect of space shuttle operation many of the experiments listed look attractive from the standpoint that a high failure risk can be tolerated if the particular experiment payoff is high enough. Another advantageous aspect of a low cost space shuttle operation is apparent for experiments which must be run a large number of times to establish a result in a statistically significantly manner.

DISCIPLINE AREA - MATERIALS, COMPONENTS AND SYSTEMS EXPOSURE EXPERIMENTS

GOALS AND OBJECTIVES FOR THE 1980'S

To perform engineering tests of the effects of the near-earth space environment upon materials, coatings, components and some simple systems using very simple, low-cost, and near-passive exposure modules. Engineering tests of the effects of the shuttle-induced environments on these materials will also be investigated.

SORTIE MODULE CONTRIBUTIONS TO MATERIALS, COMPONENTS AND SYSTEMS EXPOSURE EXPERIMENTS

Sortie missions to deliver into space and later sortie missions to retrieve from space large, simple, very inexpensive and, in some cases, near-passive exposure modules will provide a unique and cost-effective approach to investigate the effects of the combined space environment on materials, components and

systems which are planned for exposure in space on later missions for prolonged periods. The effects of the shuttle-induced environments on these materials can also be investigated by this approach.

The majority of the individual components of the space environment are thought to be simulated reasonably well in the laboratory. For example, chambers are available which can be evacuated to pressures very near the pressure which exists in near-earth space. Solar simulations are available which can very nearly simulate the solar radiation in the infrared, visible, and ultraviolet energy spectrum.

A number of facilities exist to simulate the electron and proton radiation found in space.

Facilities also exist which can combine several components of the space environment simultaneously. No facilities exist, however, which can simulate simultaneously and exactly all of the components of the space environment; thus the combined effects of all the environments may be missed in laboratory studies.

Exposure module experiments can provide a means to perform exposure experiments in the combined space environment. Data from such experiments performed on the module will be valuable as anchor-type data for evaluating laboratory test results and as final proof-type data for the performance of materials and systems in space.

Many future payloads and experiments which may be launched, serviced, and retrieved, or in some other way exist in space in the near proximity to shuttle vehicle operations, will be critically affected if any surfaces are contaminated. Optical viewing ports, mirrors, solar cells, thermal control surfaces are, to name a few, the types of surfaces which can be damaged by contamination. It is desirable to establish what types and levels of surface contamination may result from the operation of shuttle systems such as the altitude control jets and propulsion jets.

The exposure module can carry experiments to establish what contamination, if any, results from the shuttle operation required in the launch and recovery of the module. The module can also carry experiments to monitor the contamination that results during ground handling and while in the cargo bay during launch and the return trip from orbit.

Specific examples of experiments which may be carried out with an exposure module are the following which cover the areas of dosimetry, changing of insulators, exposure of electronic sensors, circuits and systems, zero gravity, material surface behavior and space environment effects on foods and their containers.

- Dosimetry — Objective: Provide a complete dosimetry for UV, charged particles, heavy ions, and temperature at various point on module. Contaminant monitoring should also be included in this effort.

- Contaminants in the Shuttle (Induced) Environment — Objective: To determine the gas environment in the vicinity of the module surface. This should include a determination of the normal environment as a baseline; however, contamination of the near-surface environment by operation of the shuttle craft or self-contamination resulting from launch and/or ground activities should receive primary attention.

- Dosimetry and Registration of Hi-Z Tracks — Objective: To further develop and study devices and techniques for monitoring the incidence of hi-Z particles, ultraviolet, and other ionizing radiation. Techniques will include: a) penetration of tracks in large AgCl crystals; b) study of hi-Z recording by etch pitting in exposed plastics and other monitor of ultraviolet; c) formation of color centers in various alkali halides.

- Shuttle Contaminant Skin Temperature Patterns High-Resolution Temperature Patterns — Objective: Obtain shuttle and shuttle payload temperature patterns. Provide appropriate temperature controls if needed.

- Contaminant Detection, Removal — Objective: To characterize and "clean" the shuttle microatmosphere.

- Space Radiation Effects in MOS Devices — Objective: Analysis of the effects produced in state-of-the-art MOS devices and special radiation-resistant MOS test structures by the space radiation environment.

- Charging of Insulators — Objective: The objective is to study the charge build-up in insulators in the space environment. Both the rate of build-up and the possibility of spontaneous breakdown due to the charge build-up are of interest.

- Exposure of Performed Cold Detectors to Space Environment — Objective: Expose one ion-type, gas-type, and momentum-type micrometeoroid detectors to space environment. After return, analyze effects of space environment on operational characteristics. Examine for impacts and/or failure modes which negate their use on long-term missions.

- The Influence of Space Environment on Contemporary State-of-the-Art Electronic Devices — Objective: To test off-the-shelf state-of-the-art

electronic devices in a real space environment. This includes digital as well as analog devices. Typically, read-only memories, light-emitting diodes, solid state lasers, microwave transistors and diodes, large-scale and medium scale integration assemblies, and various MOS-FET units will be considered.

- Solar Cell Evaluation — Objective: To test and analyze exposure of various solar cells to the orbital environment in order to ascertain their relative performance in space as well as to examine for degradation modes after recovery. A high-voltage array will be included in the test.

- Zero-Gravity Experiment with Superhigh Mol. Wt. Polymers — Objective: To prepare superhigh mol. wt. hydrocarbons such as polyethylene and polypropylene.

- Zero-Gravity Experiments - Superconducting Cpds — Objective: To examine experimentally the possibilities of synthesizing high temperature-layered superconductors.

- Solidification Under Zero Gravity (Application to Thermal Capacitor Design — Objective: The object of the experiment will be to determine if solidification of materials (metals and non metals) under a zero gravity environment is different from that occurring under normal circumstances in terms of the general morphology of the structure.

- Study of Wetting Phenomena in Metals and Ceramics — Objective: To determine the effect of zero gravity and low vacuum on the behavior of various liquids on solid surfaces. Various materials can be melted on metallic surfaces and wetting ability studied by measuring contact angles and determining surface energies.

- Rotating Condenser for Zero Gravity — Objective: To determine whether a rotating condenser offers advantages over a vapor-sweep condenser in a zero-gravity environment.

- Moisture and Heat Transport in Zero Gravity — Objective: Determination of the effect of zero gravity on the transport of moisture and heat through textile materials to a controlled temperature and humidity) atmosphere.

- Friction Adhesion and Wear in a Space Environment — Objective: The object of the experiment is to determine the long time effects of a space environment on the friction, adhesion, and wear characteristics of surfaces.

- Work Function — Objective: To determine the behavior of charge-emitting surfaces in the orbital environment as influenced by surface-potential.

- Surface Migration — Objective: To determine the degree of atomic migration which is experienced in an orbital environment on the surfaces of solids. Stresses will include structural stress as well as electric and magnetic forces.

- Evaporation/Sublimation of Solids — Objective: To obtain data on the evaporation/sublimation of solids in the orbital environment employing a variety of materials and forms of these, i.e., single crystals and films.

- The Influence of Shuttle Environment on Optical Components — Objective: To study the effects of prolonged exposure to near-earth environment upon components of an optical system. The optical system may be either passive (astronomical) or active (laser communications). The components of primary interest are: optical coatings for lens and mirrors, open photomultipliers, and solid state lasers.

- A Study of Plastic and Welding Behavior of Body-Centered Cubic and Hexagonal Close-Packed Metals Embrittled by Interstitial Atoms (Titanium, Zirconium, Molybdenum and Columbium) — Objective: To embrittle the proposed metals (Titanium, Zirconium, Molybdenum and Columium) with certain levels of interstitial atoms (Oxygen, Hydrogen and Nitrogen). Then to expose these materials to prolonged vacuum at elevated temperatures and determine the ability of the space vacuum to remove the interstitial atoms and reduce the embrittlement. To determine this improvement by studying the plastic-behavior creep testing, tensile testing and microstructure examinations would be done.

- Thermal History of Textile Materials in Space Environment — Objective: Determination of temperature maxima reached by fabrics with various thickness and emissivity/absorptivity and reflectivity characteristics.

- Production of Point Defects at Low Flux of Incident Radiation — Objective and Justification: The fates of vacancies and interstitials produced by energetic collisions depends on the dose rate. The present set of experiments aims to explore several types of systems under long-time exposure at low dose rates. Experiments would include:

  (a) production of short-range order and long-range order in low atomic weight alloys under irradiation at relatively low temperatures (i.e., $T < 400^\circ K$). The production of point defects by knock-on events would enable the system to approach equilibrium. The processes would be

monitored by measurement of electrical resistivity of wire specimens, before flight and after.

(b) growth and shrinkage of dislocation loops, voids, and stacking fault tetra hedra in quenched metal foils.

(c) study of optical properties of transparent ionic crystals of the type: Mgo, CaF_2, and doped CaF_2, where defects are produced by knock-ons.

- Long Term Radiation Aging of Adhesives — Objectives: To determine possible chemical changes that occur in high temperature as well as cryogenic adhesive such as polybenzi-midazoles, polyimides, and epoxy with age in a high radiation flux environment such as the shuttle's.

- Irradiation Effects on Synthetic Polymers — Objective: To determine the effect of various types of irradiation (UV-visible, low and high energy) on the structure and properties of polymers.

- Shuttle Unique Environment Experiments with Composites — Objective: To fabricate superior strength graphite, quartz, and asbestos-fiber reinforced high-temperature resin composites.

- Shuttle Unique Environment Experiments Involving the Crosslinking of Polyethylene — Objective: Seeking for a parallel in hydrogen plasma generated U.V. and outer space U.V. effects. If successful, a U.V. dosimeter would then result.

- Food Packaging Materials — Objective: To determine changes in chemical composition and structure of typical food-packaging materials and look for possible relationships with changes in the foodstuffs.

  Radiation degradation of packaging materials in presence of foodstuffs, synergistic effects, and changes in mechanical properties of packaging materials will all be looked into.

- Moisture Transfer and Microbiological Fermentation of Dry and Semi-Dry Food Products in the Space Environment — Objective: To determine the degree of moisture transfer and microbial fermentation in dry and semi-dry food products during the extended storage in the space environment.

- Effect of Space Environmental Storage on Food Preservation Systems — Objective: To determine the relative effect of various food preservation systems on the quality of food products stored in the space environment.

- Food Product Packaging Materials for Space Storage — Objective: To determine the effect of various packaging materials on the quality of food products stored in the space environment.

- Effect of Space Environmental Storage on Various Classes of Foods — Objective: To determine the effect of a semi-controlled space environment on the chemical and physical properties of selected types of food products during extended storage time.

- Gas Permeation — Objective: To determine the permeation rates of gases through various materials which are employed in space structures.

TITLE OF SORTIE MISSIONS EXPOSURE MODULE (MATERIALS, COMPONENTS AND SYSTEMS EXPOSURE EXPERIMENTS)

SAME AS ABOVE

1979

1981

1984

SHUTTLE-BORNE ENTRY TECHNOLOGY EXPERIMENTS

The Shuttle operational era will herald an unprecedented opportunity for finally answering many illusive questions relating to entry research — for example, boundary-layer stability. Opportunities will exist in three distinct levels of sophistication and cost.

The first level relates to those experiments which can be conducted on a minimal or no-impact basis during each shuttle mission as desired. It is particularly imperative that the agency begin preparation to exploit the opportunities afforded by the shuttle to provide the long-sought answers to fundamental problems at extremely low cost.

The second level or class of experiments will capitalize on available (excess) volume within the payload bay. This volume could be utilized either for housing instrumentation, sensors, recorders and related gear or for transport of small research entry vehicles. In the case of the entry vehicle, this additional payload would be carried piggyback without impacting the primary mission goals, thus achieving orbit with no launch cost.

The third level of complexity is represented by a major entry vehicle which would fill the available cargo volume. The Langley MURP vehicle with variable geometry for landing is typical of advanced vehicle design in which the full cargo bay can be utilized since the vehicle would have a maximum width of 15 feet with an overall length of 60 feet.

LEVEL 1 EXPERIMENTS

The primary areas of opportunities are for significant advances in the knowledge of flow fields, particularly at hypervelocity speeds, and for the research and development necessary for verification of new materials and/or techniques for thermal protection.

Flow Fields

Experimentation on a no-impact basis can offer increased understanding of real gas flows, boundary-layer transition and the associated heating, Reynolds number effects, lee-side flow, and others. Selected instrumentation including sampling probes and pressure and temperature measurements can be made in limited, carefully-chosen areas without compromising the primary goal of this phase of the mission — safe entry and landing. A typical example of the simple, yet very meaningful experiments which will be possible is typified by the photographic mapping of smoke streamers over the lee side surface (a smoke generator and escape port will be required near the canopy and camera ports near the aft end of the vehicle).

Material Verification

New materials such as radiative metallic skins can be located in selected panels (with proper backup) for actual flight test verification.

Thermal Protection Techniques

Active cooling system schemes such as transpiration cooling could also be checked in selected locations. In addition, forced coolant procedures such as the cooling by cryogenic liquid hydrogen so crucial to the development of a hypersonic transport could be verified.

These examples are not inclusive (nor has the complete feasibility been established for each individual experiment area) but merely typical of the many vital experiments that may be conducted through the capability provided by the shuttle that are crucial to the development of atmospheric flight. As it is necessary to begin now to capitalize on the opportunity for space research in orbit in the

shuttle area, preparations should also begin now to make the most of the opportunities afforded by each shuttle ascent and entry.

LEVEL 2 EXPERIMENTS

Subscale models would be used to study a wide range of flow field and material response phenomena. Most models would be unpowered and deployed for entry from shuttle. Some would have small rocket motors to allow trajectory shaping. These models would be small enough to be "piggyback" experiments that would utilize shuttle payload not required by the prime mission payload.

This piggyback approach is particularly amenable to investigation of advanced heat shield concepts, interference flow fields and heating, pressure distributions, and performance stability and control studies.

Flight test models would be used to obtain data on basic gas dynamic phenomena that cannot be obtained in ground tests. For example, accommodation coefficients could be measured for low-density flows past different virgin surface materials. Boundary layer transition at high Mach numbers could be measured with Reentry F type vehicles to extend the data to a wider range of surface-to-free stream temperature ratios, Mach numbers, and pressure gradients. Data could be obtained indicating the effects of mass addition on transition.

LEVEL 3 EXPERIMENTS

This category of experiments requires a dedicated shuttle mission to place experimental vehicle(s) in near-earth space allowing a complete reentry flight sequence. The capability for flying large scale experimental vehicles can provide relatively inexpensive proof of concept testing as well as more fundamental information. Included would be vehicles representative of advanced transportation systems, possibly employing variable geometry features, unmanned vehicle development, possibly long-duration controllable atmospheric sampling vehicles, sophisticated military decoys, and reconnaisance concepts.

In addition, a kick stage could be carried in the bay for additional velocity to permit supercircular entry. Pressure and heating rate distributions could be measured on simple shapes which lend themselves to theoretical analysis. Thus experimental data, free from tunnel effects, could be obtained for direct comparison with theoretical predictions.

Also using a kick stage, a "benchmark" radiative heating experiment could be carried out. Radiative flow-field theory has reached a high stage of development

and sophistication, but no really definitive data are available for comparison. The need for such data has long been recognized, but the high cost of flight tests (Titan III size launch vehicles are required) have been prohibitive. It would be possible to carry a propulsion system piggyback with a relatively small model and accelerate the vehicle to speeds on the order of 45,000 f/s to obtain the required data.

CONCLUDING REMARKS

SUMMARY OF POLICIES AND PROCEDURES RECOMMENDATIONS

- Documentation must be simplified, with CV-990 procedures as a goal.
- Procedures for experiment approval must be simplified utilizing the National facility approach.
- R&QA requirements must be evaluated relative to streamlining policies, relaxing standards, and simplifying procedures. Early standardization of modular equipment specifications is required so that users can purchase experimental equipment for use in ground laboratories and, subsequently, use the same equipment in shuttle missions.
- Hardware turnover should be minimized. The user should be responsible for his experimental equipment from initial purchase through installation and checkout in the shuttle/sortie laboratory.

SUMMARY OF SORTIE MISSION REQUIREMENTS

- The debris which could be introduced to the shuttle local external environment by the release of restraining clamps, payload deployments and associated pyrotechnics must be eliminated, controlled, or at least minimized.
- The shuttle internal payload bay wall temperature may reach 200°F during entry and postlanding. This high temperature will surely compromise some experimental payloads within the payload bay. Cost tradeoffs should be made relative to reducing Shuttle payload bay temperature versus additional insulation/cooling required for experiments.
- Dumping of water and other effluents must receive serious attention relative to eliminating or alleviating contamination problems.

- Remote manipulators are required. In one case, the manipulator boom must apply 200 pounds of tip force.

- Advanced power and propulsion systems development requirements (AEC/NASA) exceed current Shuttle capability to handle radiation and thermal loads. The Shuttle should be compatible with satellite power, both solar and nuclear RTG or reactors, and with high energy propulsion stages, including advanced chemical, solar electric, nuclear electric, and small nuclear rockets now being studied for geosynchronous and planetary missions for the 1980-1990 time period. The sortie mode should be utilized to define shuttle cooling and radiation shielding requirements as well as to demonstrate rendezvous and handling for radioactive or thermally-hot payloads and propulsion systems.

SUMMARY OF SUGGESTED FUTURE ACTIVITY

- The small, informal user working groups should be continued. However, the user working groups will be more productive if they can get together with the shuttle and sortie laboratory designers (MSC and MSFC engineers) for direct designer-to-user discussions and data exchanges.

- Additional active researchers with new ideas should be encouraged to participate in working groups. An attempt should be made to shift from managerial level participants to those individuals who have already submitted, or are prepared to submit, specific, definitive, shuttle experiment proposals.

- A reasonable level of funding must be provided now to permit the definition and development of experiments that are currently being proposed for shuttle sortie missions. Otherwise, the principal investigators will lose interest in proposing or developing experiments for shuttle payloads, and the agency could find itself ready to fly shuttle missions and not have a reasonable backlog of experimental payloads available.

- The NASA user presentations should be made to NASA management and the Manned Space Flight Program Office before exposure to the scientific and engineering communities of other government agencies, universities, and industry.

- The results of the recent NASA Space Research and Technology (SPART) study should be reviewed and utilized where applicable.

- Inputs from the other working groups are particularly important to the Space Technology Working Group, i.e., technological and operational requirements.

- Because of the relationships of fundamental physical principles to many technology areas, this working group considered physics and chemistry experiments in space. However, it was concluded that because of the potential for sortie experiments in this discipline a separate working group be dedicated to this future effort. Therefore, the chemistry and physics documentation is submitted separately.

- It is recognized that advanced technology activities are divided into two categories. The first is concerned with providing the design data needed to accomplish future space missions and includes spacecraft subsystems such as environmental control and life support, stability and control, electrical power, propulsion, navigation, guidance, communications, and related structures, materials and instrumentation. The second category is concerned with research on basic phenomena required as a foundation for the design of subsystems and components and research which add to the general body of scientific and engineering knowledge. It appears logical for the Space Technology Working Group to spawn additional groups or subgroups composed of individuals conducting research in the previously-mentioned advanced technology areas. As an example, a discussion of Shuttle-Borne Entry Technology Experiments has been included in this report.

  The overlap of advanced development activities of a singular discipline working group and those of an advanced space technology working group (where single efforts often benefit many disciplines) must be recognized and accounted for by division of responsibility in order to avoid costly duplication of efforts.

PHYSICS AND CHEMISTRY LABORATORY IN SPACE

At the Shuttle Sortie Workshop, physics and chemistry experiments in space were included in the Working Group on Space Technology. After discussions by the working group it was concluded that because of the magnitude and scope of the current studies for a Physics and Chemistry Laboratory in Space, and because of the potential for a substantial number of sortie experiments in these disciplines, a separate working group should be devoted to this effort. Therefore, this report is being submitted separate from the report of the Space Technology Working Group. This report was prepared by Mr. John P. Mugler, Jr., LaRC and Dr. M. M. Saffren, JPL.

The objective of the current study under RTOP 975-73-48 is to define concepts for physics and chemistry experiments in space and to develop a small number of these concepts to the point that experiment definition studies can be initiated. The study is being conducted by a study team which is composed of representatives from NASA Headquarters, LaRC, LeRC, MSFC, JPL, GSFC, MSC, and the National Science Foundation (NSF). Candidate physics and chemistry experiment concepts have been solicited from NASA Centers and JPL. These experiment concepts will be reviewed and evaluated by an Ad Hoc Advisory Panel composed primarily of members of the NSF Physics and Chemistry Advisory Panels. Experiment concepts with the greatest scientific merit will be funded for further definition and development. These initial studies will not only supply candidate experiments for early Sortie missions but also will serve as examples in our subsequent solicitation of physics and chemistry experiment proposals from the scientific community at large.

- Physics and Chemistry Laboratory in Space

- The Laboratory will support a wide range of original physics and chemistry experiments which take advantage of the unique environmental conditions in space and which are either impossible or impractical to carry out on earth.

- WALL-LESS CHEMISTRY

- Gas Chemistry Experiments in Space — Production and study of long-lived gaseous metastable species which are ordinarily lost to vessel walls on earth. Formation of excited species by irradiation by sunlight at orbital height.

- Mass and Energy Analysis of Neutral Species — Use of a simple energy analyzer to determine the composition and "temperature" of neutrals at orbital height; this determination is needed to understand the environment of neutrals in which shuttle gas chemistry experiments will be performed.

- Flame Chemistry — Generation of large mixed flames to study flame reaction in a detailed way that is impossible on earth where the vacuum chambers required for such flames would be impractical.

- Ion Beam Experiments — Study of low yield electron-ion neutralization processes by means of both crossed and merging beam experiments. On earth these low yield experiments cannot be performed because electron neutralization is masked by neutralization from charge transfer to background gases which are virtually impossible to remove from earth-based experiment chambers.

- ZERO-G DROP DYNAMICS AND ACCRETION STUDIES

- Quantum Effects in Superfluid Helium — Superfluid helium drops suspended in weightlessness will be used to study the formation of quantized vortices in superfluid helium — as well as other properties of helium — in the absence of container walls.

- Drop Dynamics and Accretion Studies — Several experiments in drop dynamics and accretion of particulates and of droplets will be performed, among which are: coalescence of drops (water drops); ice crystal formation; formation of free crystals from vapor; condensation and evaporation of drops; surface tension driven flows in fluids; study of the coupling of oscillation and vibration modes in drops; and motion of drops in thermal gradients.

- Condensation of Gases into Solids — "Inverse Sublimation" — study of condensation of vapors into freely suspended grains — condensation of vapors into solids in the absence of supporting substrates.

- Effects of Collisions on an Aggregate of Orbiting Particles — Study the conditions required to form a jet stream in an aggregate of orbiting particles. Study of the dynamics of a system of orbiting particles undergoing collision.

- FLUID PHYSICS AND HEAT TRANSFER

- Combustion in Zero Gravity — These experiments will use the long-term near-zero gravity environment to study the basic chemistry and mass transfer mechanisms in combustion processes. The results will complement current zero gravity experiments being conducted in drop towers for short test times and will extend the data to the point that realistic mathematical models of combustion phenomena can be developed.

- Critical Point Pehnomena — These experiments will use the long-term near-zero gravity environment to obtain the equilibrium and transport properties of fluids in the region of the critical point. These experiments will provide the first results free of large gravity-induced compressibility effects in the critical region.

- Pool Boiling at Low Gravity — These experiments will determine the conditions under which nucleate boiling in saturated liquids can be sustained in near-zero gravity. The results will contribute to a more complete understanding and mathematical description of boiling phenomena.

- Crystal Growth — Study the effect of compositional and thermal gradients on the growth of crystals, taking advantage of the absence of convective mixing in zero-g.

- MOLECULAR BEAM STUDIES

- Gas-Surface Interactions — These experiments will use the flux of atomic oxygen available only in space to study the physical and chemical interaction of oxygen with solid surfaces.

- (a) Wall-less chemistry facility; (b) Zero-G drop dynamics and positioning facility; (c) Molecular beam facility; (d) Fluid physics and heat transfer facility.

- Same as above.

A meaningful experiment program in the 80's and late 70's demands an aggressive development of candidate experiment concepts and an intense experiment definition effort that must begin now.

We estimate that each of the four facilities noted above would be required to fly once a quarter. This may be a conservative estimate, however. As new areas of research open up as a result of experiments performed on early missions, the interest of the scientific community can be expected to grow, and consequently more missions will have to be flown — perhaps as much as a mission a month for some of the facilities.

APPENDIX A

ADVANCED TECHNOLOGY LABORATORY

APPENDIX A

DISCIPLINE AREA

Advanced Technology Laboratory

SORTIE DESCRIPTIVE TITLE

Multidiscipline Advanced Technology Research and Development Experiments

REASONS SORTIE MODE PREFERRED

The Sortie mode is preferred over other methods for each of the potential contributions because all of the presently-proposed experiments can be performed during a 7-day Sortie mission. The nature of the research embodied within these experiments generally required evaluation of experimental results so that, if required, experimental equipment and/or procedures can be modified prior to their inclusion in a future Shuttle Sortie mission. Therefore, repetitive 7-day Sortie missions appear to be the most economical method to utilize space to accomplish the experimental objectives.

REQUIREMENTS ON SHUTTLE

The requirements on the Shuttle will not be listed here for each of the advanced technology experiments because it is deemed more realistic to consider a typical advanced technology mission with a full complement of experiments integrated into a Sortie Laboratory. Therefore, the following requirements are for a mission payload which includes 13 multidiscipline advanced technology experiments.

- Length of Flights — 7 days
- Orbit — Altitude of 200 nautical miles. Inclination angle of 60° to 90°.
- Data Requirements — Maximum data rate = 80 mbs
  Total data requirements = 36.3×10^5 mb
- Role and Number of Personnel in Orbit — Total crew time = 106 hours.

No more than one crewman at a time is required to perform any one experiment. No highly skilled specialists are required. However, some training will be

required for the crewmen to achieve a reasonable skill level in the areas of electronics, meteorology and photography.

- Stabilization and Pointing — The most severe requirement is $\pm 0.5^{\circ}$ pointing of an antenna with a depression angle of 60°, and $\pm 10^{-5}$ rad/sec stability.

- Power and Thermal — Maximum continuous power requirement = 1170 watts. Total electrical energy requirement = 208 kw hrs. Total thermal load is expected to be within the heat rejection capability of the Sortie Laboratory/ Shuttle combination.

- Weight and Volume — Total weight = 3775 lbs. Total internal pressurized volume = 167 cu. ft. Total volume required in pallet area = 679 cu. ft.

- EVA Requirements — None.

- Correlative Measurements — Limited coordination with ground truth sites required to develop the experimental technology, but no extensive correlation efforts required for implementation. Some spacecraft parameters such as altitude, attitude, and location will be required.

- General Support Equipment — TBD.

- Documentation Requirements — Minimum.

- Special Operating Constraints — No thermal dumping near deployed booms. Some externally deployed experiments sensitive to contamination by the Shuttle/Sortie Laboratory.

- Contamination Requirements — See above.

POLICIES AND PROCEDURES

Individual experimenters must have responsibility for the successful operation of their experiment. If Shuttle Sortie Laboratory is to provide easy access to space for low-cost payloads, the documentation, training and R&QA requirements must be held to a minimum.

ESTIMATED MAGNITUDE OF SORTIE USER COMMUNITY

Substantial user community composed of researchers in NASA, industry, universities, and other Government agencies.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Solicit user community in science application, exploration, and transportation for technology requirements.

RECOMMENDATIONS ON FUTURE ACTIONS

A reasonable level of funding must be provided now to permit the definition and development of experiments that are currently being proposed for Shuttle Sortie missions. Otherwise the P.I.'s will lose interest in proposing or developing experiments for Shuttle payloads, and the agency could find itself ready to fly Shuttle missions and not have a reasonable backlog of experimental payloads available.

APPENDIX B

LASER COMMUNICATIONS

APPENDIX B

DISCIPLINE AREA

Laser Communications

SORTIE DESCRIPTIVE TITLE

Laser Communications Experiments

REASONS SORTIE MODE PREFERRED

- Lower experiment cost because of capability to use some commercial rack-mounted equipment.
- Greater experiment versatility because of capability to observe data on line and to modify experiment in progress.
- Greater experiment versatility because of capability of returning payload for major modifications or experiment changes.

REQUIREMENTS ON SHUTTLE

- Length of Flight — Flights from 7-day duration up can contribute. Shuttle-deployed subsatellites can be useful with lifetime of a few weeks up to several months.
- Orbit — Not critical although for low earth orbit to ground, shuttle must pass over ground station.
- Data Requirements — Necessary for housekeeping, noting parameter changes, and measuring bit error rates. Cannot be defined accurately at this time.
- Role and Number of Personnel in Orbit — One or two persons in orbit to observe data, make experiment modifications and experiment parameter changes, and act as general "troubleshooter".
- Stabilization and Pointing — Shuttle must be reasonably stable in order to maintain a line of sight but should use CMG's or cold gas for attitude

control. Hot gas systems will contaminate an optical communications system, as it will any optical payload. The payload will provide its own precision pointing to 1 arc second or better.

- Power and Thermal -- Power requirements may range from 100 watts to 500 watts depending on exact instrumentation techniques and particular experiment. Thermal not defined yet, although ATS-G VLCE could serve as a model for requirements.

- Weight and Volume — 100 pounds up to several hundred depending on instrumentation techniques and cost.

- EVA Requirements — Not required except for possible pallet recovery in case of failure that can be fixed on board. Possible use of instrumentation airlock could alleviate this requirement and increase experiment versatility.

- Correlative Measurements -- Spacecraft attitudes and location must be known for experiment.

- General Support Equipment -- Scopes, general laboratory equipment, spectrum analyzers.

- Documentation Requirements — Not known.

- Special Operating Constraints — Attitude controlled to within limits of experiment pointing device. Could be several tens of degrees. Attitude rates not to exceed 1° per second. Attitude and location must be known.

- Contamination Requirements — Optical surfaces must be kept clean.

- Other — Unknown.

POLICIES AND PROCEDURES

Unknown.

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Unknown.

RECOMMENDED APPROACHES FOR USER COMMUNITY INTERFACING

Interface through shuttle sortie lab seems reasonable. Greatest versatility would be achieved if sortie lab is autonomous. Sortie lab should provide document of standard thermal, mechanical and power interfaces to users. Shock, vibration, acoustic, humidity, and thermal qualities in the environment should be softened as much as possible to enable user to make maximum use of standard laboratory equipment. It is recognized that the g loads caused by launch and reentry cannot be controlled; however, shuttle sortie lab people should develop standard means of protecting equipment during such loads and provide documentation to users for implementation into their experiments.

RECOMMENDATIONS ON FUTURE ACTIONS

Laser communications are presently being developed through the ATS-G program. However, independent development of devices for future systems should start now, particularly laser development. As the ATS-G VLCE program develops, much more information applicable to the shuttle sortie missions will become available.

APPENDIX C

EXTERNAL CONTAMINATION

APPENDIX C

DISCIPLINE AREA

External Contamination.

SORTIE DESCRIPTIVE TITLE

External Contamination Assessment and Abatement Mission.

External Contamination Monitors are needed on each optical-type mission. The Controlled Contamination Release Experiment would be better deployed during the sortie mode due to the short duration of exposure and the opportunities for quick data return.

REQUIREMENTS ON SHUTTLE

- Length of Flights — Applicable to any mission duration.
- Orbit — No restriction.
- Data Requirements —
  (a) telemetry from the contamination monitoring systems;
  (b) data pertaining to the performance degradation of the optical or other systems on that particular mission;
  (c) mission time of all ventings, RCS thruster firings, or other effluent events.
- Role and Number of Personnel in Orbit — None required if the data is returned by telemetry. If the data is displayed on a console, there is a requirement for this console to be monitored at appropriate times by one of the crew.
- Stabilization and Pointing — The stabilization of these instruments is not a factor in that they will probably be rigidly mounted to a portion of the shuttle or to a particular payload. The pointing directions will vary, depending upon whether the shuttle environment is being monitored or whether a particular optical system itself is being monitored. The pointing accuracy should be ±5° in azimuth and elevation.

- Power and Thermal — The power requirements of all contamination-related equipment will be on the order of 500 watts steady state and 750 watts peak. The equipment will be designed to the thermal environment within which it is located.

- Weight and Volume — The contamination monitoring equipment can be grouped into a single location for which the combined weight and volume would be 50 kg and 1 m^3 respectively. However, it is more probable that the equipment will be deployed as individual units for which the following would apply:

  (a) Integrated Real-Time Contamination Monitors, (IRTCM), 30 kg and 0.4 m^3.

  (b) Controlled Contamination Release Experiment, (CCRE), 5 kg and 0.05 m^3.

  (c) Laser Doppler Velocimenter (PV), 10 kg and 0.1 m^3.

  (d) Active Cleaning Technique, (ACT) 20 kg and 0.1 m^3.

  (e) Quartz Crystal Microbalances, (QCMs), 0.2 kg and 0.0005 m^3.

  (f) Mass Spectrometer, (MS), 15 kg and 0.05 m^3.

  (g) Active Scattering Particle Sepctrometer, (ASPS), 15 kg and 0.1 m^3.

- EVA Requirements — None required.

- Correlative Measurements — The contamination data will be correlated with the temperatures and pressures of the experiment containers being monitored.

- General Support Equipment —

  (a) Launch site — The contamination monitoring equipment will require some standard electronic test equipment such as volt meters, oscilloscopes, recorders, as well as typical laboratory tools for the installation and checkout of the flight equipment.

  (b) Aboard the Sortie Lab — An equipment console will be required for the control and display of the data from the various monitoring instruments. A portion of computer aboard will be required to precondition the mass spectrometric data prior to their being displayed or relayed to a ground station.

- Documentation Requirements — It is proposed that the documentation be reduced to the absolute minimum. It is understood that a flight unit qualification will be required to ensure against fire, odor, and other contingencies.

- Special Operating Constraints — Particular monitoring equipment, when possible, should be operating just prior to launch, during launch, and during all orbital operations. The equipment is being designed to be operated both with the shuttle cargo bay doors closed and opened. One of the purposes of some of the contamination monitors is to provide the information needed to make the decision to keep the doors closed or to open them. For this reason, some of the monitors should be located on the underneath side of one or both cargo bay doors.

- Contamination Requirements — The contamination monitoring instruments are being designed to monitor a deposition of 10^{-8} gms of material, a particle size down to 0.1 microns, 1 part in 10^6 hydrocarbons (CH_4 standard). Inasmuch as this equipment is being designed to monitor contamination, it has no contamination requirements itself once it has been placed into operation. However, before equipment is mated to those systems which are being monitored, it must be kept in an environment which is controlled to a Class 100 specification.

- Contamination Monitoring Equipment Descriptions — In general, this collection of experimental equipment is not available "off the shelf." However, the power supplies and signal conditioners could be standardized so that available commercial equipment could be utilized.

  The following instruments are currently being defined or could be defined if the requirement is firmly established.

  (a) Integrated Real-Time Contamination Monitor (IRTCM) — The IRTCM is a collection of specific instruments mounted on a pallet which will be mounted on the inside of one or both cargo bay doors. The pallet arrangement can be utilized to add, delete, or modify the individual monitors as may be required by a particular sortie mission type. The reason for having the contamination monitoring pallet on the inside of the doors is that the induced environment of the cargo bay will be monitored before the doors are opened and will also monitor the exterior environment after opening the doors.

  The bulk of the pallet is occupied by the optical effects module. This module contains a sample exposure wheel containing three optically

transmissive samples, three optically reflective samples, and three quartz crystal microbalances. The device contains a XUV source tube, a hemeillipsoid, and a movable detector. The source tube produces two monochromatic lines in the XUV. The quartz crystal microbalances are produced in such a way as to allow a reflected beam to be monitored from the same surface which is collecting deposited material. The important feature of this is that reflectance data are obtained from the identical surface which is providing mass accumulation data. The other optical samples are exposed for an amount of time which can be varied from minutes to months if needed. The exposed samples are then brought into the measuring position by rotating the sample wheel. The instrument is self-calibrating.

The other devices presently envisioned to be on the IRTCM pallet are: 1) a mass spectrometer, 2) an Active Scattering Particle Spectrometer, and 3) the Active Cleaning Technique.

The mass spectrometer has a range up to 300 AMU and a sensitivity of better than 1 part in 10^6.

The Active Scattering Particle Spectrometer (ASPS) is designed as a dual-laser, inner-cavity, scattered-radiation monitor using solid state detection. The system involves two laser tubes flange-plate mounted and sealed to assure integrity of the chamber atmosphere, thus avoiding the problem of corona discharge. The solid state detectors will be preceded by the gimballed composite of laser tubes, end mirror, scattered radiation collecting lense, and an appropriate truncation stop as necessary.

The ASPS measures particles with speeds up to 50 meters per second and sizes from 0.1 microns to 25 microns in 29 direct measurement size intervals. As an additional data output, the back DC radiation of the laser tubes, already used in the system to produce continuous calibration, will be displayed as a monitor of the deposition contamination on the exit window of the laser tubes. The ASPS is particularly suited to shuttle cargo bay contamination measurements both internally and externally and for pre-launch to orbit conditions. It is a programmed module for the proposed integrated real-time contamination monitor (IRTCM) package for the shuttle sortie missions.

The Active Cleaning Technique will be used as a part of the IRTCM as well as being installed as part of the in-situ maintenance equipment of large optical systems such as the Large Space Telescope (LST) or other optical systems which can use its capabilities.

The device operates by piping oxygen or other suitable gas to the contaminated surface of a mirror or filter. At the point of gas discharge, an RF coil generates a plasma which then chemically combines with the contaminant, allowing the resultant compounds to escape to the surrounding vacuum environment. The device will also contain an attachment to allow sputtering of the surface if the surface can tolerate such a procedure and if the contaminant can be removed in no other way.

(b) Laser Doppler Velocimeter — The Laser Doppler Velocimeter (LDV) is a focused, crossed-beam, dual-scattering system utilizing two columnated beams from a single laser which can be made to focus and intersect in any sampling volume of interest. The velocimeter detects the velocity of any moving semi-transparent medium by detecting the scattered light as the particles cross the interference fringes which are set up in the beam intersection area. Since the fringe spacing is known, the rate of intermittent scatter as the particle crosses the fringes is a true measure of particle size and velocity. The velocimeter is self-aligned and self-calibrating and produces particle velocity data up to tens of kilometers per second and particle size data from less than 0.1 microns to several millimeters. The sample volume in this velocimeter will be scanned to cover the large area of the shuttle cargo bay interior, across the opening of the bay, and experiment openings and hatches. The inspection volume can be remote from the basic instrument.

(c) Controlled Contamination Release Experiment — This experiment contains a tank of known, unique material which will be released to the environment at one or more locations and then monitored at one or more separate locations.

(d) Photometer — The Skylab contains an advanced photometer which may be appropriate for the shuttle sortie missions. If it is determined that a different or more specialized photometer is needed, one can be provided.

CHANGE IN POLICIES AND PROCEDURES

- Reduce the amount of time between initiation and flight of an experiment.
- Reduce the documentation to the absolute minimum.
- Change the Reaction Control System on the shuttle to either a cold gas or CMG system to reduce the effluents in the environment.

- Institute a procedure which ensures more experiments are available for flight than can be accommodated. Then the ones to be flown will be those which have met cost and schedule milestones.

- Decouple the shuttle launch schedule from the schedules of the candidate experiments.

SORTIE MISSION USER COMMUNITY

The induced environment data to be provided by these contamination monitors, techniques, and devices will be made available to and utilized by those experimenters using optical telescopes, other optical systems, and critical surfaces. It would appear that at least one quarter of the shuttle sortie flights will require these environmental data.

INTERFACING WITH USER COMMUNITY

The methods used on Apollo and Skylab will be continued. That is, the known users of the data are contacted directly with respect to the probable availability of the data. In turn, their requirements for specific types of contamination data are considered in the make-up of the contamination data collection system.

RECOMMENDATIONS ON FUTURE ACTIONS

- Future Planning Activities — Before the digested results of the August, 1972, Workshop is released to the scientific community outside of NASA, it is proposed that the combined results be reviewed by all participants. Future workshop participants should be more involved in the structure and procedures of the next meeting. Perhaps a more productive meeting could be achieved by having the sub-groups meet, then have a collective panel meeting, followed by more sub-group meetings, until there is a clear understanding within all sub-groups of just what is involved in the shuttle sortie concept and what advantages and disadvantages are proposed by the concept.

- The shuttle sortie experiments data bank proposed by Mr. Harry Craft should be supported. Also, the proposed study to collect the results of all previous studies should be done.

- If certain experiments are thought to be valid for the shuttle sortie mode, then the funding should be approved in order to minimize the effect of funding most of the experiments at a later date.

- Adequate SRT funds should be provided for the maintenance of the required expertise within the NASA field center which is responsible for a specific area of research. If inadequate funding is provided, this expertise will shift into other areas considered to be more important.

- Required Funding — In order to provide this package of contamination monitoring instruments, the following funding schedule is proposed.

FY 73	$ 0.6M
74	3.3
75	3.0
76	2.5
77	1.75
78	1.25
	$12.4M Initial run out

APPENDIX D

DEVELOPMENT OF LOW-COST PAYLOAD TECHNOLOGY

APPENDIX D

DISCIPLINE AREA

Development of low-cost payload technology.

SORTIE DESCRIPTIVE TITLE

- The development of low-cost payload designs which minimize program costs and increase scientific return by utilization of Shuttle capabilities.
- Launch, resupply and retrieval of unmanned lost-cost applications and space sciences payloads.

REASONS SORTIE MODE PREFERRED

The reasons the shuttle sortie mode is essential to the cost improvement approach is covered in the following sections.

REQUIREMENTS ON SHUTTLE

- Length of Flights — One to two days.
- Orbit — 200 to 400 n.m., 28° to 90° inclination.
- Data Requirements — Normal shuttle capabilities.
- Role and Number of Personnel in Orbit — Two.
- Stabilization and Pointing — Present capabilities of baseline shuttle.
- Power and Thermal — 1000 watts peak, 800 watts ave.
- Weight and Volume — 10,000 to 12,000 lbs., 12 Ft. dia., 30-40 ft. length.
- EVA Requirements — None.
- Correlative Measurements — Shuttle-based T.V. and lighting requirements; shuttle cabin display and control system adequate.

- General Support Equipment — Shuttle-based remote manipulator system, T.V. and lighting system.

- Documentation Requirements — Minimal (equal to CV-990).

- Special Operating Constraints — Longitudinal payload axis normal to sunline within ±30°. Role axis of spacecraft oriented such that solar array surface is perpendicular to sunline.

- Contamination Requirements — Payload system purged with N_2 while attached to shuttle for re-supply.

- Other — Clean dry N_2 supply for purging.

- The Shuttle C.G. — Compatible for retrieval mode with 2 OMS kits and empty cargo bay.

- Remote Manipulator Arms — Arms must have full 60 ft. reach and develop over 200 #'s of tip force.

- Shuttle Thrusters — Must be reoriented so they do not impinge on docked spacecraft.

POLICIES AND PROCEDURES

The ability to repair satellites in orbit, to update the scientific instrumentation in orbit, and to retrieve satellites from orbit for repair and overhaul on the ground will permit the application of much less exotic technology and management and documentation controls. NASA's traditional search for technical perfection, necessary since resupply or retrieval is not possible, is the root of the very high cost of present day space hardware.

Essential ingredients of low cost spacecraft development are a design that facilitates orbital resupply, refurbishment and instrument update without escalated cost, and a determined application of a development approach which simplifies those management practices and requirements that have resulted in high costs. To reap the benefits of the shuttle, overall NASA management policies must be reviewed from the top down. In addition, grass root new and unique low cost payload concepts must be initiated from the bottom up, incorporating the new policies of NASA management.

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

This low-cost payload approach is applicable to applications as well as scientific missions with cost improvement potentials exhibited agency wide.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

In order to effectively impact the present way of doing business, it is necessary that an initial low-cost demonstration prototype spacecraft be flown as a demonstrative example of the cost improvement capability of the shuttle sortie mode.

RECOMMENDATIONS ON FUTURE ACTIONS

Potential shuttle resupply concepts have been developed with the GSFC in-house design of the STAR system. The payload interfaces with the shuttle and requirements for remote manipulator design are now being studied under contract with North American Rockwell. An interim agreement with Canada provides for Canada's funding of remote manipulator design by Canadian firms as a part of this study. Both efforts consider applications as well as scientific missions. Continuation of funding in FY 73 is essential to provide the proper and timely interface requirements to the shuttle program office.

In addition, an actual engineering model spacecraft structural system is being fabricated, in-house, as a proof of some of the proposed low cost features. Funding is required for resupply demonstration tests incorporating this engineering model that have been scheduled at MSC in early September, 1972. During the tests, MSC plans to demonstrate the use of a technology development remote manipulator boom system to remove and replace spacecraft standardized subsystem modules from the spacecraft. It is essential that this type of engineering testing be continued for the purpose of validating or invalidating many of the conclusions drawn from the paper studies. Really credible cost estimates cannot be achieved by unsubstantiated paper studies.

APPENDIX E

ZERO GRAVITY OPTICAL TEST FACILITY

APPENDIX E

DISCIPLINE AREA

Zero gravity optical test facility. (Optical Technology Development Facility.)

SORTIE DESCRIPTIVE TITLE

Zero gravity flights to aid in the development and manufacture of precision optical systems for Earth Applications and Space Sciences use.

REASONS SORTIE MODE PREFERRED

See narrative on Zero Gravity Optical Test Facility.

REQUIREMENTS ON SHUTTLE

- Length of Flights -- 3 days.
- Orbit -- Any.
- Data Requirements -- Storage for recorder and film in zero gravity test facility.
- Role and Number of Personnel in Orbit -- One man for 6 hours.
- Stabilization and Pointing -- Thrusters off, crew quiet during 10 minute data-taking events. Near constant temperature orientation.
- Power and Thermal -- 600 watts peak, 400 watts average.
- Weight and Volume -- 10,000 pounds. 12 ft. dia x 36 ft. length.
- EVA Requirements -- None.
- Correlative Measurements -- TBD.
- General Support Equipment -- TBD.
- Documentation Requirements -- TBD.

- Special Operating Constraints — Stabilization for one day for test runs. Twenty data collecting events for 10 minutes duration requiring quiet, stable environment.

- Contamination Requirements — TBD.

POLICIES AND PROCEDURES

The major policy changes which must be incorporated to fully utilize this facility and in so doing achieve reduced costs are as follows:

- The willingness to use space as a development test environment for prototype space optical systems.

- The willingness on the part of management to select straightforward design approaches that are not complicated by the uncertainties of the space environment or the need for initial operational success.

- The substantial reduction in ground-based testing and analysis and the maintenance of a design philosophy which insures adequate design margins.

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

See narrative.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

The basic approach relative to interfacing with the user community for this optical checkout facility should be very much the same as the CV-990 program at ARC. The responsibility for individual instruments on optical mirror development is that of the user. The facility is provided as a support service. The integration of the instruments into the facility, their operational test schedule in flight, and the respective data reduction after flight should also be the responsibility of the user/developer. The Optical Test Facility should be developed on the basis of a flexible optical support (service) facility.

RECOMMENDATIONS ON FUTURE ACTIONS

Initially a study should be considered whereby a determination is made of the specific potential users of the facility. If it is determined that a sufficient

number of instruments and/or optical assemblies desire checkout flight opportunities, then SRT development should proceed. It goes without saying that should there not be enough demand then the entire concept should be dropped.

If the demand warrants, the facility should be developed as an OAST optical technology development facility. Utilizing a significant amount of already developed RTOP hardware, the facility can be completed for less than $8 million.

APPENDIX F

PARTICULATE MATTER IN SPACE

(METEOROIDS, COSMIC DUST AND DEBRIS)

APPENDIX F

DISCIPLINE AREA

Particulate Matter in Space (Meteoroids, Cosmic Dust and Debris).

SORTIE'S DESCRIPTIVE TITLE

Long Duration Exposure Facility

REASONS SORTIE MODE IS PREFERRED

Shuttle sortie mode is preferred first because of the return capability. Most of the active and complex measurements can be made in the laboratory after the exposure in space. The ability to observe impact damage, for example, provides much more information than automated penetration detection. The cost of the experiments is reduced orders of magnitude.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — Six to twelve months' free flying.
- Orbit — Not critical provided module has sufficient lifetime.
- Data Requirements — No telemetry — all data will be recorded on ground after exposure.
- Role and Number of Personnel in Orbit — None required other than for launch and recovery.
- Stabilization and Pointing — Not required.
- Power and Thermal — No power — module will have passive thermal control - no control required in cargo bay.
- Weight and Volume — 15,000 pounds - 14 feet in diameter by 30 feet in length.
- EVA Requirements — None.

- Correlative Measurements — None.
- General Support Equipment — None.
- Documentation Requirements — None.
- Special Operating Constraints — None.
- Contamination Requirements — None.
- Other — None.

APPENDIX G

ULTRAVIOLET METEOR SPECTROSCOPY

FROM NEAR EARTH ORBIT

APPENDIX G

DISCIPLINE AREA

Ultraviolet Meteor Spectroscopy from Near Earth Orbit.

SORTIE TITLE

Sortie Can Mission (one experiment on board).

PREFERRENCE FOR SORTIE MODE

The experiments can best be performed from a manned spacecraft with recovery capability. Man is beneficial in changing films and routine sensing of the cameras and in making preliminary evaluation of spectra. The ability to return the film for ground based data reduction is also desirable.

REQUIREMENTS

- Length of Flights — Cumulative time in space 1 year.
- Orbit — Not critical.
- Data Requirements — Return film.
- Role and Number of Personnel in Orbit — This experiment can be highly automated. The role of man is to utilize the internal control panel to initiate the experiment and to monitor instrument performance. Only one person in orbit is required.
- Stabilization and Pointing — Stabilization not critical, but unit must point to earth on dark side and attitude must be known to + or -1°.
- Power and Thermal — Less than 1 watt average - peak intermittent power of 10 watts for 1 second duration.
- Weight and Volume — 50 lbs., 4 cubic feet.
- EVA Requirements — None.

- Correlative Measurements — Attitude of spacecraft.
- General Support Equipment — Dark-room capability on module.
- Documentation Requirements — None.
- Special Operating Constraints — None.
- Contamination Requirements — None.
- Other — None.

APPENDIX H

MICROBIOLOGY (EXPLORATORY INVESTIGATIONS)

APPENDIX H

DISCIPLINE AREA

Microbiology (Exploratory Investigations).

SORTIE DESCRIPTIVE TITLE

Long Duration Exposure Facility (Microbiology Experiments).

REASONS SORTIE MODE PREFERRED

Shuttle sortie mode is preferred because of the return capability. Most of the active and complex measurements can be made in the laboratory after the exposure in space.

REQUIREMENTS

- Length of Flights — 6 months free flying.
- Orbit — Not critical provided module has sufficient lifetime.
- Data Requirements — No telemetry.
- Role and Number of Personnel in Orbit — None required other than for launch and recovery.
- Stabilization and Pointing — None required.
- Power and Thermal — None.
- Weight and Volume — 15,000 pounds - 14 ft. diameter by 30 ft. length.
- EVA Requirements — None.
- Correlative Measurements — None.
- General Support Equipment — None.
- Documentation Requirements — None.

- Special Operating Constraints — None.
- Contamination Requirements — None.
- Other — None.

POLICIES AND PROCEDURES WHICH MUST BE CHANGED TO FULLY EXPLOIT THE SORTIE MODE AND REDUCE COST

Maintain simple interface of module with shuttle and minimize testing and documentation requirements.

BRIEF ESTIMATE OF MAGNITUDE OF USER COMMUNITY

Large user community consisting of researchers in government, universities, and industry.

INTERFACE APPROACH TO USER COMMUNITY SHOULD BE THROUGH NASA RESEARCHERS IN THE FIELD

RECOMMENDATIONS

Some funding must be made available now to start definition of module and to prepare experiments.

APPENDIX I

MATERIALS, COMPONENTS AND SYSTEMS EXPOSURE EXPERIMENTS

APPENDIX I

DISCIPLINE AREA

Materials, Components and Systems Exposure Experiments.

SORTIE TITLE

Long Duration Exposure Facility (Materials, Components and Systems Exposure Experiments).

PREFERENCE FOR SORTIE MODE

Shuttle sortie mode is preferred first because of the return capability. Most of the active and complex measurements can be made in the laboratory after the exposure in space.

REQUIREMENTS

- Length of Flights — Six months free flying.
- Orbit — Not critical provided module has sufficient lifetime.
- Data Requirements — No telemetry — all data will be recorded on ground after exposure.
- Role and Number of Personnel in Orbit -- None required other than for launch and recovery.
- Stabilization and Pointing — Not required.
- Power and Thermal — No power — module will have passive thermal control - no control required while in cargo bay.
- Weight and Volume — 15,000 pounds, 14 feet diameter by 30 feet in length.
- EVA Requirements — None.
- Correlative Measurements — None.

- General Support Equipment — None.
- Documentation Requirements — None.
- Special Operating Constraints - None.
- Contamination Requirements — None.
- Other — None.

POLICIES AND PROCEDURES

Maintain simple interface of module with shuttle and minimize testing and documentation requirements.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Government researchers (NASA, Air Force, for example) and university personnel primarily.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

User community should be interfaced through NASA researchers in field rather than shuttle engineers.

RECOMMENDATIONS ON FUTURE ACTIONS

Some funding must be available now to start definition of module and preparing experiments.

APPENDIX J

PHYSICS AND CHEMISTRY LABORATORY IN SPACE

APPENDIX J

DISCIPLINE AREA

Physics and Chemistry Laboratory in Space.

SORTIE DESCRIPTIVE TITLE

- Wall-less Chemistry Facility
- Zero-G Drop Dynamics and Positioning Facility
- Fluid Physics Facility
- Molecular Beam Facility

REASONS SORTIE MODE PREFERRED

In these missions, we are taking advantage of shuttle as a transportation system to carry the experiments into space where we can exploit such unique environmental features as Zero-G, vacuum, and solar radiation. These are laboratory-type physics and chemistry experiments which require many intricate operations. These experiments typically yield little data and require man to conduct the experiment. As discussed below, it is not clear that the experimenter himself need be present in the facility.

REQUIREMENTS ON SHUTTLE

Requirements this type mission places on the shuttle if the potential contributions are to be realized:

- Length of Flights — 7 to 30 days is satisfactory.
- Orbit — As high as 350 mi.
- Data Requirements — Will be generated during current experiment studies.
- Role and Number of Personnel in Orbit — See above.
- Stabilization and Pointing — 1/2 appears to be satisfactory.

- Power and Thermal — To be determined.

- Weight and Volume — Weight and volume now envisioned appears to be adequate.

- EVA Requirements — None contemplated.

- Correlative Measurements — Will be identified in current experiment studies.

- General Support Equipment — See above.

- Documentation Requirements — See above.

- Special Operating Constraints — Drop dynamics apparatus should be located near C.G.

- Contamination Requirements — Minimize contamination in the vicinity of the shuttle.

- Other — Many physics and chemistry experiments can be put into small groups that may not require a full sortie lab. These groups could be included as part of other sortie labs.

POLICIES AND PROCEDURES

The shuttle should furnish transportation of experiments and the experimenter, his surrogate, or the ground-based facilities required to operate his experiment remotely. NASA and not the experimenter should pay for this. The experimenter must provide the experiment and should be responsible for integrating his experiment into the sortie lab. Experiments should be chosen as they now are chosen in other national facilities such as observatories, radio telescopes, nuclear reactors, and accelerators. Such facilities have users groups who determine the experiments to be performed.

The R&QA, training, and documentation requirements must be kept to a bare minimum if we are to have a workable and cost-effective sortie lab. CV 990 should be a model for handling documentation.

The results of low-cost payload studies currently underway should be included in guidelines for future payload designs. However, these results should not cause substantial additional R&QA and documentation requirements. Use of modular

components which experimenters can assemble into experiment apparatus will minimize cost, documentation, interface requirements, and R&QA. Furthermore, use of modular equipment will allow sortie lab technicians to be trained to repair standard equipment, not having to be constantly trained in ever-changing novel equipment. Modularity can also help provide standard equipment to allow for automation of experiments. Modularity will also make it less costly to provide remote control of experiments by ground-based experiments (see below for a more extended discussion of remote operation of experimenters).

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

We expect the physics and chemistry laboratory to provide easy access to space for the entire technical community of physicists and chemists, both national and international. In the U.S. alone, this group numbers well over 100,000; as a crude guess, we estimate 1 in 10 will make use of the shuttle-borne physics and chemistry laboratory by either conducting experiments in the laboratory or by analyzing data gathered in the laboratory by others.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

In the current study we are already interfacing with the NASA user community and, to a limited degree, with the academic community. In addition, the National Science Foundation is currently participating in the study with us and is assisting in evaluating the scientific merit of experiment proposals. In the future, we are considering more extensive involvement by the National Science Foundation as well as involvement by the National Academy of Science.

RECOMMENDATIONS ON FUTURE ACTIONS

DEVELOPMENT OF EXPERIMENTS

A meaningful experiment program in the 80's and the late 70's demands an aggressive development of candidate experiment concepts and an intense experiment definition effort that must begin now.

REMOTE OPERATION OF SORTIE EXPERIMENTS BY GROUND-BASED EXPERIMENTERS

The required training of an experimenter if he wishes to fly on shuttle will deter many potential experimenters who are, after all, busy men. Furthermore, experimenters may not be willing to entrust operation of their experiment to others. Moreover, even if an experimenter does entrust operation of his experiment to others, it will be difficult and time consuming to train the person who will fly. For these reasons there should be provisions made for remote operation of sortie lab experiments by experimenters stationed on the ground. Such a provision would make the use of shuttle much more attractive to experimenters, thereby increasing the market for shuttle use.

Another reason for providing for remote performance of sortie experiments is the cost of providing large sortie labs and the life support and rescue facilities able to accommodate many experimenters. It may be more cost effective to have only two technicians who could perform simple operations and carry out equipment repairs. They would not have to be trained to do any experiments.

Providing such an "all-up" remote control capability will be extremely expensive. However, if it helps attract many more experimenters than would otherwise use the shuttle, this cost would be partially justified. Furthermore, the cost would be defrayed by the use of such remote control systems on RAM which is to follow the shuttle sortie lab, and on space station which is to follow RAM. Remote control for Space Station would require only a few men to be actually present on space station.

MATERIALS PROCESSING AND SPACE MANUFACTURING
PRELIMINARY REPORT OF THE WORKING GROUP

CONTENTS

	Page
INTRODUCTION	2-1
SUMMARY PROGRAM PLAN	2-2
THE SHUTTLE SORTIE MODE'S POTENTIAL CONTRIBUTIONS TO MS/MS PROGRAM PLANS AND OBJECTIVES	2-4
REQUIREMENTS ON SHUTTLE SORTIE MISSIONS	2-9
POLICIES AND PROCEDURES	2-13
ESTIMATED SIZE OF THE MS/MS USER COMMUNITY	2-14
RECOMMENDATIONS	2-16

MATERIALS PROCESSING AND SPACE MANUFACTURING
PRELIMINARY REPORT OF THE WORKING GROUP

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INTRODUCTION

DISCIPLINE OBJECTIVES FOR THE 1980'S

Space Accessibility

Make space easily accessible to the international scientific and industrial community for research and development work in materials science and technology.

Development of Techniques

Develop techniques that take full advantage of the characteristics of space flight to achieve experimental and process conditions that are not obtainable at competitive costs on Earth.

Application of Techniques

Employ the novel materials research and development techniques that are possible in space to acquire new knowledge in technologically important areas of materials science and technology.

Technological Advancement

Apply Research and Development results obtained in space to advance materials technology generally and, in particular, to invent processes to manufacture products in space for use on Earth.

Application of Manufacturing Processes

When appropriate, reduce selected space manufacturing processes to practice and conduct pilot production operations to demonstrate their practicality.

Development of Space Commercial Production

When capabilities to manufacture economically viable products are achieved, initiate commercial production operations in space.

SUMMARY PROGRAM PLAN

The Materials Science and Manufacturing in Space (MS/MS) program's plans for accomplishing the objectives stated above fall into four phases, as follows:

INITIATION

With the resumption of manned space flights in the late 1970's, the program's primary tasks will be to introduce the scientific and industrial materials Research and Development community to the technical opportunities offered by space and also to develop techniques for materials Research and Development work that take full advantage of those opportunities.

The limited precursor experiments that will have been accomplished on the Skylab and ASTP missions will provide a group of up to 20 scientists and engineers with some practical experience of materials work in space. In the early years of the new st program, however, it will be necessary to build up a user group of at least two participating scientists and engineers, both to make reasonable progress toward the program's objectives and to achieve full utilization of the space shuttle's resources.

Therefore, much of the program's space activity in the early years of shuttle operations will comprise preliminary experiments by materials scientists and engineers who are new to space work. Much of this work will involve the development and refinement of experimental methods and apparatus, and we expect that the average experimenter will require time on several flights to complete his research program.

RESEARCH AND DEVELOPMENT

Within a few years, the program is expected to reach a state in which large number of scientists and engineers are involved in its space activities and techniques are well established in its major areas of effort. Additions of new participants are then expected to fall to a rate about equivalent to the attrition due to completion of closed-end research projects. Effort devoted to new techniques and apparatus will drop to the level dictated by requirements that cannot be met by previously established methods.

The distribition of effort between materials research and process development will be largely determined by the interests of participating scientists and engineers in this period since the MS/MS program's principal needs will be to stabilize the user group recruited in the previous phase and to foster creative work that can lead to economically viable space manufacturing products and processes.

REDUCTION TO PRACTICE

At some point in the middle 1930's, the program should have identified some space manufacturing products and processes with enough potential to warrant trials of production operations. It is possible that commercial entrepreneurs may wish to invest in this activity, but it seems more likely that the initial trials must be wholly or largely funded by NASA because they will break new ground in equipment development and space operations.

It is anticipated that approximately three years will be required to develop and shake down the integrated space and ground facilities needed for pilot production of one or a few initial products. Thereafter, pilot-scale production will continue until full-scale production operations begin or decisions are made not to continue with non-viable products.

During this period, Research and Development activities are expected to continue at a level of effort at least as high as that established during the preceding phase.

COMMERCIAL PRODUCTION

By the end of the 1990's, we hope to have demonstrated that full-scale space manufacturing operations will be commercially feasible for at least one product or process. It is expected that private investment will enter the picture in significant amounts during the late stages of pilot operations for the first such

products, and that arrangements to institute full-scale production will include only as much Gevermnent investment as is appropriate to NASA's role as a developer of space technology.

It should be noted that initiation of full-scale manufacturing operations will not supersede either Reasea h and Development activities or pilot production operations. In fact, the levels of effort in both categories will probably increase and involve a rising proportion of private investment when it becomes evident that space manufacturing is practical and profitable.

THE SHUTTLE SORTIE MODE'S POTENTIAL CONTRIBUTIONS TO MS/MS PROGRAM PLANS AND OBJECTIVES.

It is generally believed that the space shuttle's seven-day sortie missions can provide a highly versatile and effective means of carrying out the first two phases (Initiation and Research and Development) of the Materials Science and Manufacturing in Space program's plans for the 1980's. At least the first part of the third phase (Reduction to Practice) can be accomplished on 30-day missions, but the late stages of pilot production and the initiation of the commercial manufacturing phase will probably require shuttle-supported continuously-operating orbital spacecraft.

EARLY PHASES

Through the first two phases of effort described above, the shuttle will serve the MS/MS program most effectively if it can provide very frequent flight opportunities for relatively small payloads. Most of the program's participating investigators, or Research and Development teams, are expected to engage in continuing projects in the following general areas: Metallurgy, Crystal Growth, Glass Technology, Biological Applications, Physical Processes in Fluids, and Chemical Processes.

Within each area different investigators will have many common equipment requirements, and different areas will also share some requirements. The MS/MS program proposes to meet these requirements by building up an inventory of modular, general-purpose equipment that can be configured flexibly to meet the needs of all participants with minimum additions of special fixturing for particular experiments.

However, during the early period of shuttle operations the MS/MS program will have to expand its user group considerably and support its users' work on developing effective methods for Materials Research and Development in Space.

Although the program's foreseeable equipment requirements will be studied extensively during the 1970's, the amount of actual space data available for such studies will be very small compared to what can be derived from even the first year of shuttle operations. Since new users are likely to develop many fresh requirements in their early efforts on the shuttle, the MS/MS program's most effective and economical course will be:

- to develop only enough equipment before the first shuttle flights to engage the interests of users and support their initial experiments, and

- to carry on apparatus development concurrently with the shuttle experiment program so as to build up an inventory of equipment that supports users' current needs.

Under this policy, the MS/MS program's payload equipment inventory will evolve continuously toward increased capabilities, and the apparatus to be provided at the outset will be planned mainly to furnish satisfactory initial conditions for the evolutionary process that is to follow.

Thus, the MS/MS program will begin the period of early shuttle operations with equipment modules that can be assembled in many different ways to make up payloads serving different needs, but the whole collection will probably not be large enough to make up a full payload for a dedicated sortie mission. In addition, the program will be seeking to serve a very diverse and rapidly growing user group whose members will have little in common initially except pressing needs for early flight opportunities.

It will be extremely important to make flight opportunities easily accessible to the MS/MS user community early in the shuttle flight program in order to attract materials scientists and engineers into space work and enable them to get satisfactory results without long delays and excessive coordination requirements. This can be accomplished most easily if the program takes advantage of the flexibility of its equipment to configure partial payloads for flight on substantially all of the early shuttle missions.

Current planning literature suggests that on many, if not most, of its missions the shuttle will fly with rather large weight margins. It is anticipated that further operations planning will show that many missions will also have significant crew timeline margins within the nominal seven-day mission duration. This seems especially likely on missions where the shuttle functions as a launch vehicle and may have to remain on station with its daughter spacecraft during extensive ground-controlled checkout periods.

Because of the very diverse nature of its subject matter, the MS/MS program can probably provide experiment payloads that would be compatible with virtually any primary shuttle payload and could make nearly full use of the shuttle's residual resources on any mission. Naturally, it will be most economical to provide payloads for manned operation in most areas of interest. However, some types of experiments, such as diffusion-controlled crystal growth from solutions, may require such long times and low acceleration levels that they must be performed on free-flying unmanned satellites. Also, if the available carrying capacity furnishes a sufficient incentive, it should even be feasible to assemble automated payloads that could operate in unpressurized bay space with their own power sources and radiators.

We, therefore, propose that the MS/MS program should utilize every shuttle flight as if it were a sortie mission, whether the flight carries a sortie lab or not. If the shuttle proves to be sufficiently flexible for this mode of operation, the MS/MS program can gain access to the frequent flight opportunities and payload space required by its objectives, virtually without impact on the shuttle's ability to meet other programs' requirements.

Frequent flights of relatively small MS/MS payloads early in the program will afford many opportunities for hardware economy, maximize users' flight opportunities, and help to maximize utilization of the shuttle. In addition, the MS/MS program will have enough flexibility in this mode of operation to exchange shuttle payload space and mission time with other disciplines that may need to fly equipment either earlier or later than originally anticipated. Therefore, the program can act as a kind of "flywheel" to help ensure that the shuttle can fly on a regular schedule with full payloads, in spite of the multiple contingencies that will affect payload availability.

At some point in the Research and Development phase described above, we expect that the MS/MS program's user community and apparatus technology will mature to the point where dedicated sortie missions will become the most efficient mode for its further operations in some areas. The total level of MS/MS effort in space will probably exceed the equivalent of more than one dedicated mission per year when this point is reached, and much of this activity is likely to involve sharing of sortie lab space with other disciplines. Therefore, the initiation of dedicated MS/MS sortie flights will involve a reorganization of some of the program's space activities rather than an expansion of effort.

The transition to dedicated sorties will probably come when the program has grown to include substartial process development activities aimed at demonstrating the feasibility of specific products. This type of effort can operate on the somewhat rigid schedules we foresee for dedicated missions more easily than exploratory research, which must work more or less at its own pace to be most

effective. Thus, the first dedicated MS/MS flights will probably be organized mainly for process development. On the other hand, the dedicated missions will have specially trained MS/MS payload specialists, and this will be a considerable advantage for the more sophisticated types of research experiments. We therefore expect that the program's early dedicated missions will include some research activities, although the bulk of its research will probably continue to use shared space on other missions to gain the advantages of high flight frequency.

Adequate flight frequency can be obtained with dedicated MS/MS missions if the program's total effort rises to a level that can use three or four sorties per year. As long as the maximum mission duration remains at seven days, however, the cost advantages of sharing space on other missions will probably cause the program to restrict its dedicated mission activity to those cases where resource requirements exceed what can be obtained on shared missions.

With the advent of thirty-day missions, the cost effectiveness situation may alter in favor of dedicated sorties. By this time the program's apparatus technology will have matured enough so that much of its research equipment will be in routine use without needing frequent modification. The MS/MS user community will probably have stabilized as well, so that most participants will be engaged in long-term projects that can function effectively with flights on a prescribed schedule. Many of the program's process development activities will have reached the point where refinement of process conditions rather than basic equipment development is their main concern. Thus, the program may have developed the capacity to use thirty-day missions effectively at about the time when they become feasible, and in this event their cost advantages over multiple seven-day missions will become overriding. In addition, sortie missions sponsored by the other disciplines are likely to have much less payload space available for sharing when those disciplines go over to thirty-day mission durations.

THE PHASE OF REDUCTION TO PRACTICE

The MS/MS program's pilot production operations will begin when processes are fully developed for some highly promising products. At this time the question of their economic viability must be settled. It is highly unlikely that this question can be answered for any product by production on a laboratory scale, because manufacturing costs and operating procedures can only be defined with sufficient precision by operations on a scale approximating what is necessary for commercial production.

These considerations will apply with special force to space manufacturing, where previous commercial experience will provide next to no guidance on a wide variety of crucial questions. In order to manufacture finished products that

involve processing in space, it will be necessary to set up ground facilities to prepare materials for space processing, orbital facilities to carry out the process steps that must be performed in space, and ground facilities to finish the space-processed materials and integrate them with other components of the final product. The operation of these facilities must be integrated, which will pose many unusual problems in production scheduling and material flow, equipment maintenance, procurement and marketing, and even labor relations. In addition to settling these operational issues, the pilot production operations must validate a wide variety of technical choices made during the development period, such as equipment designs, the degree of manned involvement in production processes, and safety provisions before the commitment to full-scale facilities is made. Finally, the features of government-industry relations that affect operating costs will require trial production operations for their accurate assessment.

With so many questions to be settled, it is not to be expected that the MS/MS program's initial pilot plant operations will be routine or quickly concluded Several short missions will probably be required to check out and shake down pilot space facilities before production runs can begin, and production will probably have to proceed for some time before the combined space and ground facilities begin to operate together smoothly enough to yield convincing information on operating economics and the products' ability to meet market price and performance requirements.

Dedicated shuttle sortie missions are likely to provide the best means of performing equipment shake down runs and intermittent operations to make ready for consistent pilot production, but it is not certain that missions with a thirty-day time limit can adequately support actual production. If continuous output is a necessity, the completion of pilot operations may have to wait until it becomes possible to place production facilities permanently in orbit.

THE COMMERCIAL MANUFACTURING PHASE

At this time it is impossible to foresee very clearly just what space manufacturing operations will be like. Conceivably they might be supported by sortie missions if the associated ground operations can work with intermittent supplies of space-processed materials and if the space processes involve relatively large amounts of material and physically small processing equipment. However, it appears more probable that most processes will work most economically with highly-automated, continuously operating facilities in orbit, using the shuttle to transport personnel, supplies, and processed materials.

Thus, it seems likely that the space manufacturing program may be among the first to generate firm requirements for a permanent orbital space station. In its early years of operation, this station may be too small to require full shuttle payloads for its logistic support, so that visits would be needed from the shuttle on missions flown for other purposes. Because of this, the station may develop a subsidiary function as a way-station to "warehouse" hardware that is used in orbit but does not need to be returned to the ground after every use. Ultimately, however, manufacturing operations in orbit are expected to build up a factory complex large enough to require regular dedicated sortie missions to service them. The space factory will probably have passed into full private ownership by then, and its dedicated logistic service seems likely to become a commercial operation within a few years of its initiation.

REQUIREMENTS ON SHUTTLE SORTIE MISSIONS

At this early stage of development, the requirements that the MS/MS program will place on shuttle sortie missions can only be stated in general terms. A preliminary view adapted from data contained in NHB 7150.1 (Reference Earth Orbital Research and Applications Investigations), Vol. VI, and modified to fit anticipated shuttle resources is given in Section X of Aerospace Report No. ATR-72(7312)-1, Vol. II (NASA Payload Data Book, Payload Analysis for Space Shuttle Applications (Study 2.2) Final Report), prepared by the Aerospace Corp. under Contract No. NASw-2301. More detailed studies are currently being performed by the TRW Systems Group under Contract No. NAS8-28938, Requirements and Concepts for MS/MS Payload Equipment. Interim results from this study can be provided as required for other planning activities, and a final report will be available in June, 1973.

The following data are given to provide a summary of the program's approximate requirements pending further definition, and are therefore to be regarded as subject to change.

MISSION DURATION

On the average, MS/MS experiments to be performed on the shuttle sortie missions are expected to take from three to eight hours per run. However, trial production runs may have to extend over considerably longer times. Also as noted above, some specialized experiments may have very long durations of the order of 1000 hours so that they must be performed on free-flying satellites deployed and later retrieved by the shuttle.

C2

ORBITS

MS/MS payloads will have no requirements for special orbital altitudes or inclinations with one exception — sun-synchronous orbits will be needed if any attempts are to be made to use solar heat to process some materials.

DATA REQUIREMENTS

The prime sources of data for MS/MS experiments will be digital tape, still and motion picture film, and processed materials returned to Earth for analysis. Most data requirements can be met by returning records to Earth for post-flight analysis, but two-way television may be needed for experiments where crew involvement is high and interaction is required with investigators on the ground.

ROLE AND NUMBER OF PERSONNEL IN ORBIT

The MS/MS program's early experiments are expected to consist mainly of the application of prescribed procedures to samples of material supplied by investigators, requiring only simple setups of apparatus in flight and no alterations of experiment protocol during any single run. As is the case in the program's Skylab experiments (M551 through M566), process conditions during most experimental runs will be under automatic programmed control with practically all handling of the apparatus and samples within the capabilities of a simple tape-controlled industrial manipulator. Full automation of the program's early experiments will therefore be a feasible option. It is expected to be cheaper to design the apparatus to be set up and reconfigured as necessary by the shuttle crew, however, since only simple mechanical skills will be required for the early experiments.

Requirements for manned involvement are likely to increase as the program's experiments increase in sophistication and its experimenters learn to use the crew's services resourcefully. Two-man experiment support crews will probably suffice for most missions, but some extremely diversified dedicated payloads may require up to four men to exercise all of their equipment fully.

In all operations we can visualize at present, the role of payload specialists in MS/MS experiments will be to act as skilled laboratory technicians rather than as primary investigators. It may prove worthwhile to qualify some investigators to fly who are deeply involved in developing new techniques so that they can gain first-hand experience of the shuttle's operating enviroment, but for other purposes trained astronauts will be the better choice.

STABILIZATION AND POINTING

The MS/MS program's prime operational requirement is for a low acceleration enviroment, since all of its activities will be based on exploitation of the weightless conditions that are available in space. The sensitivities of different experiments to acceleration will vary widely, but the average experiment is expected to require that accelerations from all sources be held at or below 10^{-4} g (i.e., about 0.1 cm/sec^2).

Experimenters will have a general preference for mounting their apparatus near the spacecraft center of gravity to minimize the effects of rotational accelerations. Consideration should also be given to incorporating low-level thrusters in the shuttle design to minimize attitude control accelerations.

Individual experiments will have no special pointing requirements. However, as noted below, sortie missions carrying MS/MS payloads will tend toward maximum electric power consumption and heat rejection requirements. If the shuttle's radiator system requires a particular orientation under maximum load conditions, MS/MS experiments will usually require that the spacecraft assume that orientation.

POWER AND THERMAL REQUIREMENTS

The power requirements of individual MS/MS experiments will generally fall between 100 and 1000 watts in the program's early phases, when experimental samples need only be large enough for scientific analysis. However, each payload will comprise multiple experiments with modular apparatus, so that great latitude will exist to adjust the total power consumption or heat rejection rate to available capacity. Since the shuttle's foreseeable weight margins appear to be rather large, the amounts of MS/MS equipment that can be included in missions carrying other primary payloads will probably be controlled by fuel cell and radiator capacity. Therefore, if a large disproportion exists between the latter and the shuttle's weight margins, the MS/MS program may find it profitable to develop its own palletized power sources and radiators to be flown in payload space.

In the late stages of process development, when larger quantities of material must be processed, MS/MS payload power requirements are expected to rise to the order of 10 kw. Pilot and full scale production operations will have still larger power and heat rejection needs which will have to be met by resources in the payload rather than in the shuttle.

WEIGHT AND VOLUME

As noted above, we expect the size of MS/MS payloads to be limited by the shuttle's power resources rather than by its carrying capaeity. We estimate that the equipment for a dedicated sortie lab capable of using all of the shuttle's electric power would weigh no more than 5000 lb. and occupy no more than 500 cubic feet. With modular equipment, a continuous range of smaller payloads could be made up, extending virtually to zero weight and volume.

EXTRAVEHICULAR ACTIVITY

No operational requirement is foreseen for EVA since any manipulations to be performed in unpressurized space will be exactly prescribed and therefore easily mechanized. However, it might be well to have EVA capabilities available to deal with minor malfunctions that could be corrected in flight.

CORRELATIVE MEASUREMENTS

All data recorded during MS/MS experiments will need to be keyed to accurate times and measurements of rotation rates and accelerations in all six degrees of freedom. Other housekeeping data will probably be needed as well and should be available on the shuttle's data bus. We foresee no requirement for shuttle-provided measurements of conditions outside the spacecraft.

In addition to real-time data, it would be convenient if the shuttle data system could provide continuously updated forecasts of future maneuvers and of power and heat rejection capacity to the MS/MS payload's automatic control equipment. If these were available it would be comparatively simple to give the payload capabilities to schedule its activities for optimum resource utilization in real time.

GENERAL SUPPORT EQUIPMENT

Requirements in this area cannot be defined until the MS/MS program's payload equipment studies have proceeded further.

DOCUMENTATION REQUIREMENTS

It is anticipated that the MS/MS program can operate successfully with whatever documentation scheme the shuttle program may require.

SPECIAL OPERATING CONSTRAINTS

As noted above, MS/MS payloads may place constraints on the shuttle's orientation if special orientations are required for maximum heat rejection.

The normal spacecraft acceleration enviroment will probably be satisfactory for most experiments, but some extremely sensitive experiments may require occassional special operations to provide ultra-low accelerations.

CONTAMINATION

Unless the program decides to use solar concentrators to provide process heat on sun-synchronous missions, its experiments will not be sensitive to the shuttle's external enviroment. Many experiments will use vacuum apparatus that will be vented to space, but since the internal cleanliness of this apparatus will be critical to the experiments, it will be easy to ensure that only oxygen, nitrogen, and inert gases are vented.

POLICIES AND PROCEDURES

ALLOCATION OF PAYLOAD SPACE

Since economical operation of the shuttle will depend to a large extent on its maintaining a regular schedule with full payloads, the shuttle program should be primarily responsible for space allocations and flight scheduling. In line with this responsibility, it should keep all of the discipline program offices informed on a current basis of mission launch dates and resources currently available on each future flight. Payload scheduling and priorities should be periodically reviewed by an agency-wide shuttle Missions Board having the authority to resolve conflicts between program offices or direct changes to reflect national policy, but actions to obtain flight assignments should be handled directly between the discipline program offices and the shuttle program.

ACCEPTANCE OF EXPERIMENTS FOR FLIGHT

Flight opportunities will cease to be uniquely valuable events when the shuttle reaches operational status. Therefore, the decision to develop and fly particular experiments should rest with the discipline program offices, under control exercised by the cognizant Associate Administrators through the budgeting process.

FLIGHT QUALIFICATION

The responsibility to qualify experiments and apparatus for flight on the shuttle should rest with the organization (which may not be a NASA program office) seeking space on the shuttle. This responsibility should be considered to have been met if the proposed payload passes acceptance tests prescribed by the shuttle program.

PRIVATE USE OF THE SHUTTLE

As early as possible, services by the shuttle should be made available to private organizations that are willing to pay their fair shares of mission costs. Private requests for shuttle services should be subject to competent review by agency management, but organizations whose requests are approved should not be subject to any extra qualification requirements and should receive full title to any results they obtain from their space activities.

ESTIMATED SIZE OF THE MS/MS USER COMMUNITY

The user community in the fields covered by the MS/MS program is potentially enormous, since it includes materials, scientists, and engineers of all descriptions. Involvement can be expected from many areas, ranging from pharmacology to ferrous metallurgy, and it will be worldwide. In quantitive terms, it can be pointed out that in the United States alone there are upwards of 90,000 chemists, including 15,500 on the faculties of colleges and universities, approximately 12,000 physicists in materials related fields, 13,709 members of the Metallurgical Society, and 6000 in the American Ceramic Society. On a worldwide basis, it seems conservative to estimate that the MS/MS program's shuttle activities will touch the professional interests of between 200,000 and 300,000 scientists and engineers, and the technology interests of virtually every materials related industry.

As we have pointed out above, direct participation in the shuttle program will involve only a small fraction of this group and is likely to take several years to develop fully after flights begin. However, the published work of the direct participants in the program will reach the entire community outlined above. If all goes well, we can expect this work to show the international scientific and industrial community that the shuttle represents a resource for new materials technology that no organization can afford to ignore. As this realization becomes widespread, it could conceivably create a demand for the shuttle's services far exceeding the most optimistic of current projections.

INTERFACES WITH THE USER COMMUNITY

In the early phases of shuttle operations, MS/MS space experiment activity will be strongly oriented toward research and development, most of which will be Government funded until such time as the promise of space manufacturing is proved sufficiently to attract private investment. Therefore, the program will have much of the character of normal Government supported Research and Development with a rather high usage of GFE facilities, the only material difference being that some of the facilities will be in space.

User interface procedures for this kind of activity are well developed and will need only one major change to adapt them for efficient shuttle utilization. The MS/MS program will serve as a discipline oriented sponsoring office to solicit experiment proposals, select experiments to be performed, and sponsor supporting research and development. In view of its plans to use its apparatus repeatedly for different experiments and its need for continuous apparatus development, the MS/MS program should also be responsible for developing all of the payload apparatus required for its activities. Thus the shuttle program's relation to the MS/MS program would be that of a supplier of space transportation services to a user organization with needs for such services; we recommend that this relation should be governed by the policies and procedures outlined in the preceding section on that topic.

As the MS/MS program progresses toward pilot production operations, some of its space activities are likely to take on the character of cooperative ventures with industry. Arrangements for such joint programs will have to be defined on an agency-wide basis by NASA's legal and policy-making bodies, and it is to be hoped that a suitable background of administrative precedent will evolve out of the conduct of relatively small scale joint experimental activities before the need for pilot production operations arises.

We recommend that the MS/MS program should act in the capacity of NASA's agent to make the direct arrangements for cooperative projects in its discipline area, and that its interface with the shuttle program in these cases should be the same as in projects that are wholly Government funded. On the other hand, it seems appropriate that any industrial user organization wishing to fly its own payloads wholly at its own expense should deal directly with the shuttle program on an independent basis. In such cases the MS/MS program should act only as a source of any technical advice the shuttle program might need, and should not be called upon to perform any functions that would compromise the outside user's proprietary interests.

The same considerations would apply to full-scale production operations. If such operations are a joint venture between NASA and another user organization, then

the user interface should be handled between the MS/MS program and the shuttle program. If production is undertaken independently by a non-NASA organization, however, that organization should deal directly with the shuttle program to obtain the latter's services.

RECOMMENDATIONS

The following actions on the part of the shuttle program are recommended to support implementation of the plans outlined above:

- The shuttle's payload accomodations should be designed so that worthwhile corollary payloads can be carried to utilize the vehicle's residual resources on missions where the prime payload leaves significant margins. Since most of the development and operating costs of the shuttle will be associated with its ability to lift weight into orbit, consideration should be given to organizing on-board utilities such as power, data systems, radiators, etc. so that the full lifting capacity can always by utilized.

- In its design work and operational planning, the shuttle program should ensure that each of the discipline offices is aware of what is being done to meet all of the others' requirements, so that they can assess potential conflicts and will be made aware of the full range of flight opportunities that may be available.

- Beginning early in both programs, the shuttle and sortie lab contractors should be directed to assign liaison engineers to keep the discipline offices informed of work in progress, so that the latter can express their concerns over developing problems or recommend action to grasp unforeseen opportunities to the NASA shuttle program management on a timely basis.

- In order to serve the MS/MS program effectively, the shuttle should be designed so that it can provide acceleration levels no higher than 10^{-4} g in normal operations and can control accelerations to levels below 10^{-6} g by special operations.

- An early decision should be made regarding responsibilities for discipline payload equipment development, so that the individual discipline offices can begin to make firm plans for their SRT and payload development programs for the 1970's.

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REPORT OF THE
COMMUNICATIONS AND NAVIGATION (C&N)
WORKING GROUP

CONTENTS

	Page
GOALS & OBJECTIVES	3-1
POTENTIAL SORTIE CONTRIBUTIONS	3-1
SORTIE MISSIONS	3-2
SPECIAL SORTIE MISSION REQUIREMENTS	3-3
POLICIES & PROCEDURES	3-3
RECOMMENDATIONS	3-4
EXPERIMENT TITLE: TERRESTRIAL RF SIGNAL SOURCE LOCATION (1a)	3-5
EXPERIMENT TITLE: RFI CHARACTERIZATION (1b)	3-8
EXPERIMENT TITLE: RADIATION COOLED RF POWER AMPLIFIER COLLECTOR (2a)	3-10
EXPERIMENT TITLE: OPERATION OF OPEN, HIGH POWER, RF AMPLIFIER IN SPACE (2b)	3-11
EXPERIMENT TITLE: LARGE DIAMETER ERECTABLE ANTENNA (2c)	3-12
EXPERIMENT TITLE: DEMONSTRATION OF SPACE COOLED LOW NOISE RF AMPLIFIER (2d)	3-13

CONTENTS (Continued)

Page

EXPERIMENT TITLE:
MILLIMETER (MM) WAVELENGTH COMMUNICATION LINKS (3a) 3-14

EXPERIMENT TITLE:
10.6-μm LASER DATA RELAY LINK (LDRL) (3b) 3-16

EXPERIMENT TITLE:
HIGH DATA RATE NEODYMIUM LASER COMMUNICATIONS EXPERIMENT (3c) 3-18

EXPERIMENT TITLE:
GROUND-BASED NAVIGATION AID CHECKOUT (3d) 3-19

EXPERIMENT TITLE:
DEMONSTRATION OF SPACE REFERENCED TRAFFIC MANAGEMENT SYSTEM (3e) 3-20

EXPERIMENT TITLE:
ON-BOARD DATA PROCESSING (3f). 3-21

EXPERIMENT TITLE:
BANDWIDTH CONSERVING MODULATION/DEMODULATION (3g). 3-22

B

REPORT OF THE COMMUNICATIONS AND NAVIGATION (C&N) WORKING GROUP

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GOALS & OBJECTIVES

The goal of the C&N discipline during the era of the Space Shuttle transportation system will be to increase the use of space systems and develop new space capabilities for providing communication and navigation services to the user community in the 80's and 90's.

To meet this goal NASA will need to identify potential future C&N space applications, working in conjunction with the user. It must develop the systems concepts that will facilitate the application of space technology for improving existing techniques of communicating voice and data information between earth, air and space terminals; and improving the present and planned navigation, traffic control and position fixing methods of aircraft, terrestrial vehicles and spacecraft.

Finally, our objective is to demonstrate, in cooperation with the user community, the utility of space technology and systems to meet their needs. We want then to obtain experience with the technology in a quasi-operational environment.

POTENTIAL SORTIE CONTRIBUTIONS

After reviewing the experiments proposed, the Working Group (W.G.) selected those that: complement the on-going NASA C&N program by filling gaps in experiment data and technology development, involve man in a necessary and relevant manner, and are not repeats of experiments which can be done equally well via automated spacecraft.

The W.G. further determined that the sortie design and mission capability provides a practical vehicle for conducting certain C&N experiments, and that the sortie mode of operation will reduce the time, risk and cost for conducting experiments and developing technology leading to eventual automated system application. The large weight carrying feature of the sortie system facilitates ease of comparative test evaluation between alternative subsystems, components and techniques. The shuttle return capability enables the experimenter to perform evaluation of the space environmental effects on his experiments in the comfort of his ground-based laboratory.

SORTIE MISSIONS

Based upon this first cut of NASA experiment ideas in C&N for sortie flight, it does not appear that dedicated sortie missions will be required. Rather, C&N will be a partial user of the sortie's space availability. Many C&N experiments will desire specific orbits, mission duration, subsatellite ejection, etc. These mission requirements are listed under each of the experiments in the appendix.

A number of experiments in Communication and Navigation should be conducted early in the sortie program because their results will have a direct bearing on the experiments of other disciplines. Some examples follow:

- The on-board data processing experiments is one that offers the potential for reducing the communications bandwidth required for transmitting large amounts of data to earth. Early successful development tests of this technology may therefore significantly reduce the required frequency bandwidth for some other discipline experiment.

- Successful development of a large erectable communication antenna having high gain values on early sortie missions may significantly affect the design of other experiments. An antenna of such size will provide improved signal-noise and high data rate capabilities and/or decrease requirements on instrument design.

- Early mapping of the radio frequency interference in the sortie orbit may help to reduce potential experiment jamming and improve experiment useful output.

A number of C&N experiments are planned to be performed in conjunction with proposed future automated geostationary orbit missions. Therefore, the date of some C&N sortie flight experiments is dependent on successful operation of these geostationary missions.

SPECIAL SORTIE MISSION REQUIREMENTS

Under each of the experiment descriptions in the appendix is listed special sortie requirements. A summary list is provided below:

- Air locks
- Contaminant sensors
- Increased incremental primary power supply 3-6 Kw
- EVA
- High voltage testing in sortie labs
- 3-axis secondary platform stabilization to about 5 arc-seconds
- Stabilized controllable sub-satellites
- Flip-over of shuttle for part of mission
- 30 day mission
- Accurate sortie ephemeris data
- High degree inclination
- High altitude orbit
- Experiment antennas on orbiter

POLICIES & PROCEDURES

The introduction of the sortie mode of operation, with its large volume and weight carrying capabilities, affords NASA the opportunity to consider different ways of selecting payloads. Some policy problems are listed below:

- Encourage non-NASA institutions (private industry and other government agencies) to propose experiments for sortie flight in which they would pay for the experiment hardware. A policy is needed for handling experiments considered proprietary by industry and what NASA expects from the industry as to the disclosure of experiment results. NASA must continue to retain experiment approval authority.

- Encourage industry to propose experiments for sortie flight where they pay for the experiment and the space they occupy in the sortie. Again a policy is needed relative to the disclosure of proprietary data resulting from the flight experiment, and arrangements if the experiment must be taken off a flight for some reason.

- Consideration should be given to assigning a lead center for management of specific "facility" type experiments. This will require the lead center manager to obtain user requirements from the technical community, design and develop the instrument, and bring it to the launch pad. Data analysis will be done by investigator teams, selected in advance, who will also provide technical guidance to the lead center manager.

- Consider a plan to develop a backlog of experiments that can ride on the sortie when mission parameters and space are available.

USER COMMUNITY-MAGNITUDE

The potential C&N user community for sortie experiment flight, data return, technology developments and subsystem tests will consist of the total aerospace community, almost every NASA Center (KSC & FRC expected), some government agencies, a small number of University scientists (less than a dozen), and foreign scientists representing their government, university, and industry organizations.

USER COMMUNITY INTERFACE

The Shuttle Sortie capabilities and constraints should be made available to the user community in a simplified booklet form that they can employ in initial experiment design write-up. NASA should encourage technical papers in the open literature read by appropriate discipline personnel; such as: IEEE Proceedings & Aeronautics and Astronautics. NASA should also arrange for a meeting with industry, university and foreign senior scientists and engineers to inform them of the potentials for experiments on the sortie.

RECOMMENDATIONS

- Provide FY 73 funding for early definition of selected experiments

- Provide early implementation of 30 day mission capability

- Implement standard capability for precise attitude control of secondary platforms or devices
- Encourage technical community to use sortie lab facility
- Form inter-center communications-navigation orbiter-sortie interface working group
- Provide capability to monitor received signal level and power spectrum on all orbiter radio receivers.

In addition to the above listed recommendations the working group felt that a common sortie laboratory design that could handle a wide variety of diverse experiment discipline instruments is highly desirable. The basic equipment in the laboratory should be common to many disciplines. Minor modifications will be acceptable for different missions.

EXPERIMENT TITLE: TERRESTRIAL RF SIGNAL SOURCE LOCATION (1a)

OBJECTIVE

To develop the technique of using satellites to aid in frequency management and planning by locating and characterizing terrestrial RF sources from an orbiting lab.

RATIONALE

Effective use of the frequency spectrum depends upon a knowledge of the location, frequency spectrum, and power of terrestrial transmitters together with the statistics on their use with time. Present information is inadequate for the task, and data gathering methods are too costly to completely cover the areas where frequency management is needed. Use of a satellite to obtain data on RF sources allows measurement over all terrestrial areas of interest.

EXPERIMENT DESCRIPTION

A low noise receiver connected to an earth facing antenna receives the signal energies transmitted by terrestrial sources. A calibrated spectrum analyzer is used to determine frequency, power level, and bandwidth.

Table
Experiments

	Mission Duration (days)	Major Location		Pointing		Orbit	
		Lab	Exterior	Earth	Space	Incl	Alt
1. Characterization Experiments							
RF Environment Mapping							
1a. Signal Source Location	30	X	X	X		H	H
1b. RFI Characterization	30	X	X	X		H	H
2. Components							
High Power Transmitters							
2a. Radiation Cooling	7		X		X		
2b. Open Envelope	30	X	X	X			
2c. Large Diameter Erectable Antennas	30		X		X		
2d. Space Cooled Low-Noise RF Amplifier	7		X				
3. Systems/Techniques							
Spacecraft to Spacecraft, Spacecraft to Ground Communications							
3a. MM Waves (reentry Plasma Com, Thruster Plume EF)	30		X		X		H
3b. 10.6μ Laser	30		X		X		H
3c. 0.53μ Laser	30		X		X		H
3d. Ground Based NAV Aid Checkout	7	X		X			
3e. Shuttle Reentry NAV	7	X		X			
3f. On-Board Data Processing	7	X		X			
3g. Bandwidth Conservation	7	X					H

The frequency range of interest is from 100 MHz to above 20 GHz. To cover this frequency range several different antennas and receiver front ends are required. A dual beamwidth antenna (wide beam and narrow beam) is required. Location of the source to within 5 Km is based upon satellite position and altitude and the antenna pointing angles. Several missions may be used to cover different frequency ranges.

EQUIPMENT

Antennas (dual beamwidth)	Antenna Platform Control
Receiver	Data System for Analyzer and Antenna Platform

Receiver Front Ends (Swept Freq)

Spectrum Analyzer

Size: 1 m^3 within Sortie lab, antennas external to lab

Weight: 200 kg

Power: 700 w

Flight Date: 1979

SPECIAL REQUIREMENTS

- 30 day minimum mission duration
- High altitude orbit, high inclination
- Antenna pointing to within $\pm 0.1°$
- Large Antenna

EXPERIMENT TITLE: RFI CHARACTERIZATION (1b)

EXPERIMENT OBJECTIVE

To characterize the RFI environment generated by terrestrial sources over a complete sphere and to establish the validity of using this data to predict the terrestrially generated RFI fields at any orbit altitude.

RATIONALE

Communication system planning and design for satellites and spacecraft depends upon a knowledge of the RFI fields that are viewed by the spaceborne receiving antennas. Frequency, magnitude, and direction of arrival of the fields are required to make optimum choices of frequency, power, and transmission format. Measurement of the RFI fields over an entire sphere surrounding the earth would allow, through use of a mathmatical model, calculation of the RFI fields at any other altitude.

EXPERIMENT DESCRIPTION

A low noise receiver connected to an earth facing antenna receives the RFI generated by terrestrial sources. The antenna has two axis gimballing to allow determination of the direction of arrival of the signals. A calibrated spectrum analyzer measures magnitude and frequency of the received signal. Several antennas and receiver front ends are required to cover the frequency range 100 MHz to 20 GHz. At any given frequency, the data obtained may be used to generate a model consisting of elements of a sphere, each element radiating with the power and direction as measured by the satellite. The validity of using the model to determine the RFI at any altitude is verified by an orbit change or by later flights.

EQUIPMENT

Antennas	Antenna Platform w/2 axis
Receiver Front Ends (swept freq)	Data System for Analyzer & Antenna Platform
Receiver	
Spectrum Analyzer	

Size: 1 m^3 within Sortie lab, antennas external to lab

Weight: 200 kg

Power: 800 W

Flight Date: 1979

SPECIAL REQUIREMENTS

- 30 day minimum mission duration
- High altitude orbit, high inclination
- Antennas on gimballed platform for sweeps on 2 axis
- Large antenna

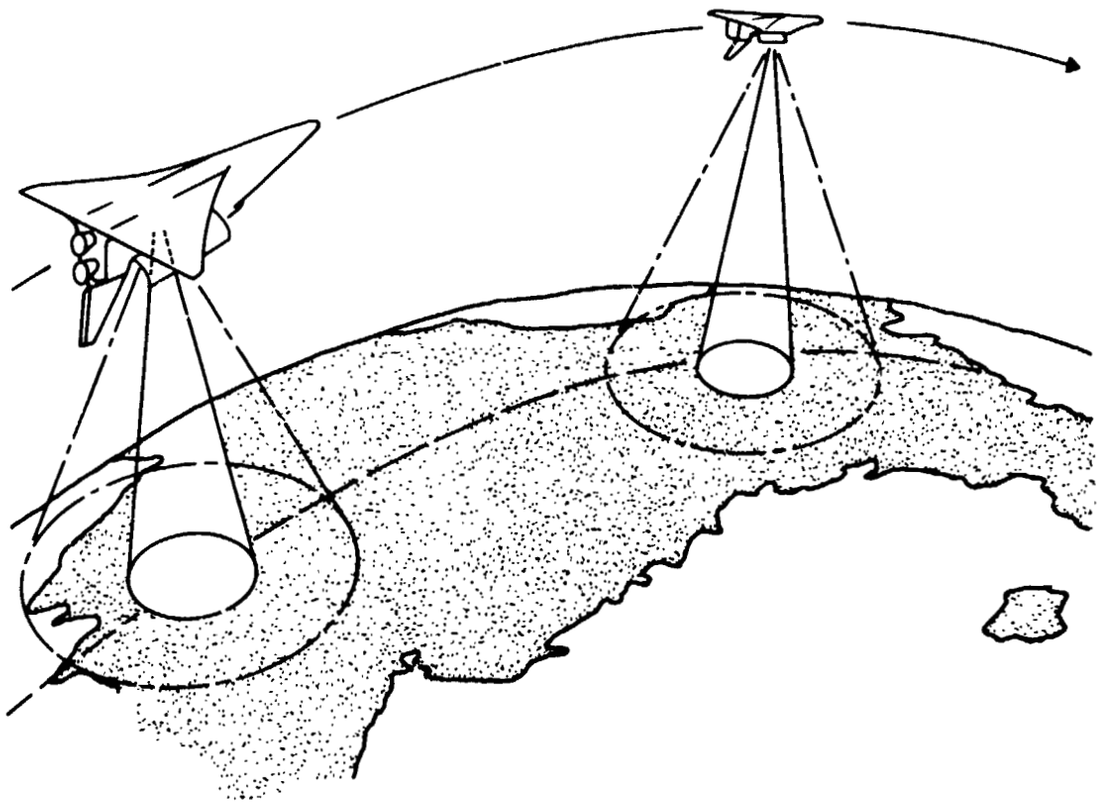

Figure 7-1. Measurement of Terrestrial RF Sources of Noise and Interface

EXPERIMENT TITLE: RADIATION COOLED RF POWER AMPLIFIER COLLECTOR (2a)

OBJECTIVE

To establish the operational possibility of using direct radiation cooled collectors for multi kilowatt RF power amplifier tubes in satellites.

RATIONALE

A significant design problem associated with the operation of high power RF amplifiers on spacecraft is the disposal of the waste heat developed at the electron beam collector. A potential solution is to operate the collector at red hot temperatures and radiate the heat directly to cold space. Radiation cooled collectors have been successfully operated in the laboratory but have required a sapphire vacuum window. When operating in space it may be possible to operate without the window and achieve high radiation efficiencies.

EXPERIMENT DESCRIPTION

The experiment would be performed in conjunction with experimental operation of a tube with open vacuum envelope. After opening the tube outside of the sortie spacecraft the operating characteristics of the tube would be measured, including the thermal distribution of the collector and associated tube structure including the radiation efficiency. Hardware required includes high voltage power supplies, voltage and current meters, RF power source, RF power meters, thermo couples, optical pyrometer, and data recorder.

Size: 2 m^3

Weight: 40 kg

Power: 4 Kw

Proposed flight date: 1979 to 1981

SORTIE SPECIAL REQUIREMENTS

- Air lock with platform extendable to orbiter envelope

- Seven day operation adequate
- One operator to manipulate instrumentation

EXPERIMENT TITLE: OPERATION OF OPEN, HIGH POWER, RF AMPLIFIER IN SPACE (2b)

OBJECTIVE

To determine the feasibility of operating high power RF amplifier tubes which are open to the space atmosphere in the vicinity of a spacecraft located outside of the Earth's atmosphere.

RATIONALE

Some communication applications such as satellite broadcasting will require long life operation of multi-kilowatt (11.7 to 12.5 GHz) RF power amplifiers in Earth satellites. The life of these tubes is shortened by contamination from internal outgassing. The opening of the vacuum envelope to space may be a feasible low cost method of pumping such tubes thereby prolonging the life. On the other hand, material in the vicinity of the spacecraft may contaminate and destroy the tube cathode.

EXPERIMENT DESCRIPTION

The experiment would consist of measuring the performance of several tubes before and after opening the vacuum envelopes and then resealing and returning the tubes to an earth laboratory. On earth the internal content of some tubes would be analysed while others would be life tested and compared with ones that were not opened to space. Hardware required includes high voltage power supplies, voltage and current meters, RF power source, RF power meters, spectrum analyses and data recording.

Size: 2 m^3

Weight: 40 kg

Power: 4 kw

Proposed flight date: 1979 to 1981

SORTIE SPECIAL REQUIREMENTS

- Air lock with platform extendable to orbiter envelope
- Gaseous, ionic and particulate contamination instrumentation
- Up to 30 day operation
- One operator to open vacuum seal and manipulate instrumentation

EXPERIMENT TITLE: LARGE DIAMETER ERECTABLE ANTENNA (2c)

OBJECTIVE

To observe the erection characteristics of competing large diameter erectable spacecraft antennas and to measure the static and dynamic surface characteristics.

RATIONALE

Many discipline areas such as communication satellites, broadcast satellites, tracking-data relay satellites, and Earth and ocean dynamics have use for spacecraft antennas of more than 5 meters. Although antennas up to 9 m diameter are feasible, the development of efficient, low cost deployment mechanisms can be aided by direct observation and manipulation by man. In addition man in orbit can make direct observation of surface deformations to determine the quality of the antenna. Candidate mechanizations are conical reflectors and rib-mesh structures.

EXPERIMENT DESCRIPTION

The experiment would consist of erecting the antenna, observing and photographing the action, measuring the surface tolerances and electrical performance. The measurements would be made under various lighting conditions to determine the effect of thermal gradients. In addition to the antenna, hardware would include special tools, photogrammetric instruments, cameras, and antenna gain measurement instrumentation.

Size: Uncertain volume - depends on antenna size. 10 m is a reasonable diameter

Weight: 100 kg

Power: 500 w

Proposed flight date: 1980

SORTIE SPECIAL REQUIREMENTS

- Pallet
- EVA
- One operator, one observer

EXPERIMENT TITLE: DEMONSTRATION OF SPACE COOLED LOW NOISE RF AMPLIFIER (2d)

OBJECTIVE

To demonstrate possibility of radiation cooling a low noise RF amplifier for a spacecraft radio receiver.

RATIONALE

The efficiency of repeater type communication satellites is partially dependent on the noise figure of the satellite receiver. FET's are understood to be available with low noise characteristics when cooled to low temperatures. By this means up to 2 dB signal to noise ratio improvement could be achieved at typical C band communication satellite receivers.

EXPERIMENT DESCRIPTION

After suitable ground development and testing, an amplifier would be exposed from the sortie so that it would be cooled by direct radiation to space. The operating characteristics would be measured with special attention to measurement of the noise temperature. This would be measured when the amplifier is connected alternately to an antenna and a calibrated radio noise source. In addition to the amplifier, equipment needed includes, RF signal source, noise

temperature receiver, modest antenna, calibrated noise source, associated microwave transmission circuits, and data recorder.

Size: 2 m^3

Weight: 30 Kg

Power: 500 w

Proposed flight date: 1980 or 1981

SORTIE SPECIAL REQUIREMENTS

- Air lock with platform extendable to orbiter envelope
- One operator to manipulate instrumentation

EXPERIMENT TITLE: MILLIMETER (MM) WAVELENGTH COMMUNICATION LINKS (3a)

OBJECTIVE

To evaluate and demonstrate by actual satellite tests, the communication potential of the millimeter wave bands (27.5-31 GHz and 54-190 GHz) for space/space communication links. Investigate the suitability of these bands for space/ground communications during the spacecraft atmospheric re-entry phase (radio blackout phase) of the mission.

RATIONALE

To meet the ever increasing demand for information transfer it is essential to exploit higher and higher frequency bands which provide the additional bandwidth required by high data rate communications. In the last decade the 1-10 GHz band has been extensively exploited for operational communication systems and the 12-14 GHz band is planned to be intensively investigated during the 1970-80 period. The above millimeter bands have been allocated for space utilization at the 1971 WARC and their potential needs to be developed. Millimeter wave propagation test data from ATS-F & G missions will provide essential baseline data for detailed sortie experiment design.

EXPERIMENT DESCRIPTION

In common with optical communication links between moving spacecraft, a major problem concerns the development of signal acquisition techniques and frequency and spatial tracking systems to establish and maintain the link. Also, it is necessary to determine the effect of spacecraft thruster exhaust products on signal absorption, and the effects of electron density on wide-band phase coherence. Equipment for these experiments can also be used for investigating the use of these frequencies for communication through re-entry generated plasmas to ground terminals.

Prime test modes for space/space link evaluation include:

- Subsatellite transmission to the sortie lab,
- Two-way transmission, sortie lab to subsatellite to sortie lab,
- Sortie lab to earth.

The basic equipment requirements for the sortie lab are:

- Precision narrow-beam antennas with high performance tracking mount,
- MM wave transmitters and receivers,
- pseudo-random code generators,
- error comparators,
- power meter,
- wide-band modulators,
- waveguide patching panel,
- digital tape recorder,
- spectrum analyzer,
- digital counter
- power supplies.

Size, weight and power requirements can only be crudely estimated at present. Four standard electronic racks, each weighing approximately 200 lbs. are the present estimates. The total power consumption would be on the order of 2 KW. A lower frequency band MM wave experiment (27-31 GHz) would be available for flight experiment in 1980; the higher frequency bands (54-190 GHz) will probably be investigated in the 1983-85 period since much technology development must precede flight testing.

SORTIE SPECIAL REQUIREMENTS

The space/space link tests require an attitude controllable (from sortie lab) subsatellite whose orbit with respect to sortie is not presently defined. There are no sortie special requirements for sortie orbit altitude or inclination. It is highly desirable to conduct MM wave experiments concurrently with laser link tests thereby utilizing a common subsatellite and attitude stabilization platform on a 30 day mission. There will be a need for controlled sortie thruster firings for plume attenuation measurements. Astronaut participation is essential for radiated power level adjustments, modulator interchange and adjustment, spectrum monitoring and photographing, and experiment coordination. Plasma propagation test definition is dependent upon shuttle re-entry characterization.

EXPERIMENT TITLE: 10.6- μm LASER DATA RELAY LINK (LDRL) (3b)

OBJECTIVE

To develop and test a system to provide 400-MBps communication capability between a low-altitude satellite and a synchronous satellite with a spacecraft terminal weight of 60 lbs and a prime power requirement of 125 watts.

RATIONALE

In 1979 or later it is likely that a synchronous satellite will be active which carries a 10.6- μm Doppler-tracking, laser heterodyne receiver. This receiver will be extensively exercised from a ground station which will simulate a low-altitude satellite performing a data-relay operation. A space shuttle experiment will provide a relatively low-cost test of the LDRL under actual space-to-space conditions. The development of this capability will meet NASA's requirements to service high data-rate earth observational spacecraft for the next decade beyond 1980.

EXPERIMENT DESCRIPTION

The synchronous satellite receiver is not discussed here. Laser Transmitter on Space Shuttle:

Wavelength: 10.6 μ m (28 000 GHz)

Prime Power: 125 W

Carrier Power: 1 W

Modulation Mode: Double Sideband Suppressed Carrier

Modulation Format: Digital, Non-Return-to-Zero (NRZ)

Modulator Bandwidth: 220 MHz

Antenna Gain: 92 dB

Antenna Diameter: 5 in. (12.5 cm)

Antenna Coverage: Hemisphere

Weight: 60 lbs

Size: 2 cu. ft.

Operator: Deploy and direct system during acquisition

Stabilization: $\pm 0.1^\circ$ or better

SORTIE SPECIAL REQUIREMENTS

Telescope must be deployed ouside sortie. Synchronous satellite terminal must be available. As noted above $\pm 0.1^\circ$ stabilization is required to reduce acquisition time. A two-week mission is adequate for proof testing after extensive synchronous satellite to ground tests.

EXPERIMENT TITLE: HIGH DATA RATE NEODYMIUM LASER COMMUNICATION EXPERIMENT (3c)

OBJECTIVE

Evaluation of the performance of a laser digital communication system over low orbiting-to-synchronous and low orbiting-to-ground links.

RATIONALE

Increasing data rate requirements for earth-observational systems may outstrip the capabilities of conventional telemetry within the next decade. The neodymium laser system can accommodate bit rates of 4×10^8 sec^{-1} at present and has growth potential to the multi-gigabit per second rate. The use of optical frequencies permit such systems to be implemented with a transmitter antenna diameter of 10 cm.

EXPERIMENT DESCRIPTION

This task will use the major subsystem components such as solid-state lasers, photomultiplier detectors, beam steerers, optical trackers, and high speed digital electronics and integrate them into a high speed (400 M/Bits) optical communication terminal. This unit, in conjunction with the laser ground system being developed in-house at GSFC, will be utilized to evaluate the high data rate communications link through space-to-ground and space-to-space channels. The space to space tests will be conducted with both NASA and DOD synchronous terminals. The manned capability aboard the satellite terminal will increase experiment value through flexibility in modulation format, optical alignment, and acquisition and tracking techniques. Component stability requirements can be relaxed with significant cost-savings by employing in-flight calibration.

Performance/Hardware Characteristics

- Transmitter Wavelength - 1.06 micrometers
- Transmitter Antenna Diameter (Beamwidth) - 10 cm (2 arc-seconds)
- Data Rate (Error Probability) 4×10^8 sec^{-1} (10^{-5})

- Total Power - 85 watts
- Total Weight - 23kg (51 pounds)

SORTIE SPECIAL REQUIREMENTS

Operator Time: 5 hours per week

Platform Stability: ±10

Mission Duration: 2 weeks (minimum)

EXPERIMENT TITLE: GROUND-BASED NAVIGATION AID CHECKOUT (3d)

OBJECTIVE

To demonstrate the ability and desirability of being able to determine the operational status of gound-based navigation equipment from orbit.

RATIONALE

This experiment is part of the overall objective of using space to improve traffic management services. The FAA in this country has many ground-based installations for aircraft navigation and control. An extensive aircraft flight program is maintained to check the operational status of these systems. The experiment would determine if it is economically practical to perform some of these checks from orbit.

EXPERIMENT

The sortie would include receivers, transponders and other test equipment similar to that now carried by the test aircraft. A narrow beam antenna would be used for spatial resolution.

SORTIE MISSION REFERENCE

The man's capability is required to recognize the gound systems to be checked and to operate the antennas. Some of the other spacecraft equipment might be

more economically inplemented using the man for operation. The ability of the sortie to fly over a prescribed ground track is desirable.

COMMENTS

Low altitude coverage to get in the radiation patterns of the ground-based navigation aids in the continental U.S. and Europe is a primary interest. Coverage of other areas of the world is desirable.

EXPERIMENT TITLE: DEMONSTRATION OF SPACE REFERENCED TRAFFIC MANAGEMENT SYSTEM (3e)

OBJECTIVE

To assess the ability of Pseudo-random noise (PN) satellite ranging systems to position fix and provide data for the shuttle from take-off to orbit and back to landing.

RATIONALE

To demonstrate the use of multiple satellite techniques for near-time frame three dimensional positioning and navigation of aircraft, maritime vessels and future space transportation systems. Aircraft flight will be desirable prior to spaceflight.

EXPERIMENT DESCRIPTION

One or, preferably, several geo-stationary satellites will be utilized to feed through an L-band PN coded signal from a ground based source to the shuttle. A navigation receiver-processor located on the shuttle will be utilized to provide position and velocity data that can be compared with other position fixing data (i.e. laser trackers in the orbit phase and actual survey data and other ground based trackers during the landing and take-off phases of flight) to determine the capabilities of this system in various geometrical formations.

	Equipment Required	Performance
Total weight - 100-200 lbs.	Receiver-Processor	Position accuracy 1 to 5 meters
Volume 30 ft.^{3}	Computer Display	Velocity accuracy 0.1 meter/sec
Power 100 watts	Recorder	Resolution factor of 10 over accuracy
	Antennas (6 in. long)	

SORTIE SPECIAL REQUIREMENTS

Need to utilize sortie through entire flight, therefore need external antennas not in normal payload enclosure.

COMMENTS

System could serve as back-up operational navigation system.

Men might be utilized to view the display unit and compare with other shuttle navigation systems to provide inputs on the operational quality of the data.

EXPERIMENT TITLE: ON-BOARD DATA PROCESSING (3f)

OBJECTIVE

To demonstrate the characteristics of several data compression algorithms using real data sources and real satellite links.

RATIONALE

Several disciplines such as astronomy and earth resources indicate a potential need for transmission of large quantities of data from 1 to 100 Mbps. Because of RF bandwidth constraints it is desirable to demonstrate to users the characteristics of various data compression algorithms. The experiment would make

comparative measurements using real data and would use the ability of man to change algorithms and make equipment adjustments as the experiment proceeds.

EXPERIMENT DESCRIPTION

The experiment would consist of using data from representative sensors such as a multi-spectral scanner and process the data to remove redundancy and code it for radio transmission. The coding equipment would be either programmable or modular so that a variety of algorithms and coding techniques could be demonstrated. In addition, provision would be made to adjust parameters such as decision thresholds or word lengths as the experiment progresses. The equipment would consist of a representative instrument, digital processing equipment, data recording equipment, and data transmission equipment.

Size: 5 m^3

Weight: 100 kg

Power: 2 kw

Proposed flight date: 1980

SORTIE SPECIAL REQUIREMENTS

- Manned operator
- High data rate recording equipment
- High data rate transmission equipment Mbps.

EXPERIMENT TITLE: BANDWIDTH CONSERVING MODULATION/ DEMODULATION (3g)

OBJECTIVES

Establish and measure the characteristics of experimental communication links using high data rate digital transmission techniques that conserve RF bandwidth.

RATIONALE

The needs for high data rate digital communications for information networks will place increasing demands on precious radio frequency allocations. Modulation/demodulation techniques such as multiple phase shift keying and multiple amplitude shift keying have the potential for achieving coding gains in signaling efficiency at only modest cost in RF bandwidth utilization. They are thus applicable to satellite information network designs. The purpose of the experiment is to make comparative performance measurements on real links after suitable theoretical development and laboratory simulations have been performed.

EXPERIMENT DESCRIPTION

The experiment would consist of establishing data links between ground stations via transponders in the sortie laboratory. Test data would be transmitted for the purpose of measuring error characteristics. The links would use various modulation forms including uncoded phase shift keying, multiple phase shift keying and multiple amplitude shift keying. The transponder would be implemented from modular laboratory type equipment that could be readily configured and adjusted by an astronaut for each modulation/detection techniques. The equipment would include a modular transmitter- receiver, noise temperature monitor, signal generators, antennas, spectrum analyser, modulators and demodulators.

Size: 4 m^3

Weight: 300 kg

Power: 2 kw

Proposed flight date: 1980

SORTIE SPECIAL REQUIREMENTS

- High inclination, high altitude orbit desireable for long observation passes.
- 7 day mission o.k.

REPORT OF THE EARTH AND OCEAN PHYSICS WORKING GROUP

CONTENTS

	Page
INTRODUCTION	4-1
SOLID-EARTH DYNAMICS/EARTHQUAKE MECHANISMS	4-1
POTENTIAL CONTRIBUTIONS OF SORTIE MODE	4-2
TITLE OF SORTIE MISSION	4-2
FLIGHT SCHEDULE	4-3
OCEAN DYNAMICS	4-3
POTENTIAL CONTRIBUTIONS OF SORTIE MODE	4-4
TITLE OF SORTIE MISSIONS	4-4
FLIGHT SCHEDULE	4-4
APPENDIX A SOLID-EARTH DYNAMICS/EARTHQUAKE MECHANICS	4-A-1
APPENDIX B OCEAN DYNAMICS	4-B-1

REPORT OF THE EARTH AND OCEAN PHYSICS WORKING GROUP

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INTRODUCTION

This Shuttle Sortie Workshop comes at an opportune time for the Earth and Ocean Physics area. The Office of Applications is currently completing a program plan for a new Earth and Ocean Physics Applications Program (EOPAP) covering the period 1974 to 1982. The shuttle sortie mode can provide direct support to that program and its extension in two ways; i.e. by providing launch services for those EOPAP satellites planned for flight subsequent to 1978, and by serving as a test bed for the development and evaluation (particularly intercomparisons) of candidate remote-sensing instrumentation for later satellite missions.

The following pages summarize how the sortie mode can contribute to EOPAP.

It should be noted that the instruments and supporting requirements listed for test-bed missions are based on our current knowledge; they are not intended as final definitive requirements, but rather as representative classes of instrumentation to satisfy the remote-sensing needs of the discipline. As additional progress is made in understanding the needs of the discipline and the phenomena under investigation, the instrumentation requirements may change.

SOLID-EARTH DYNAMICS/EARTHQUAKE MECHANISMS

GOALS AND OBJECTIVES

To obtain a better understanding of the dynamic processes of the solid earth as they relate to earthquakes, with the goal of hazard assessment and alleviation.

The following phenomena are included: tectonic plate structures and motions, fault motions, polar motion and earth rotation variations, solid-earth tides, structure and temporal variations of the earth's gravity and magnetic fields as they relate to the earth's internal structure and dynamical processes, volcanic and geothermal phenomena.

POTENTIAL CONTRIBUTIONS OF SORTIE MODE

- To provide a test-bed and observational platform for new instrumentation techniques, such as: precision imaging multi-frequency radars, FM correlation radar for baseline measurements, side-tone ranging system, multi-frequency laser and microwave differential refraction experiment, and a laser ranging/altimeter experiment.

- To use man as an observer for correlation with the remote sensing, and to use his judgment to provide flexibility in the observing program and in the use of the equipment.

- To launch short-lived satellites to demonstrate the applicability of these techniques.

- To launch short-lived satellites for operational observations.

TITLE OF SORTIE MISSION

- Test-bed flight to evaluate the following instruments:

  Precision imaging multi-frequency radars

  FM correlation radar for baseline measurements

  Side-tone ranging system

  Multi-frequency laser and microwave differential refraction experiment

  Laser ranging/altimeter experiment

- Free-flying satellite deployments

  Vector magnetometer satellites. Three polar orbit, low-altitude (400 km), separated by four hours local time, operating simultaneously for six months. One monitor satellite at 1000 - 2000 km, inclinations between 0 and 28°.

Drag-free gravity satellites; two satellites, separated by 200 km, polar orbit, altitude 200 km.

Gravity-gradiometer satellite, polar orbit, altitude 200 km.

Dense laser reflector satellites, 300 - 1000 km, different inclinations.

FLIGHT SCHEDULE

1979 . launch 1 GEOPAUSE satellite (polar, 1000 kg, 30,000 km)
. deploy 1 pair drag-free gravity satellites
. 1 test-bed mission

1980 . deploy 1 gravity-gradiometer satellite
. deploy 6 dense laser-reflector satellites in different orbits and inclinations
. 1 test-bed mission

1981 . deploy 3 low-altitude magnetometer satellites in polar orbits separated by 4 hours in local time
. deploy 1 medium-altitude magnetic-monitor satellite

1982 . 1 test-bed mission

1983 . 1 test-bed mission

1984 . 1 test-bed mission

1985 . 1 test-bed mission

1986 . deploy 3 low-altitude magnetometer satellites in polar orbits separated by 4 hours in local time
. deploy 1 medium-altitude magnetic-monitor satellite

1990 . same as 1986

OCEAN DYNAMICS

GOALS AND OBJECTIVES

To identify and monitor for a better understanding of ocean dynamic phenomena such as currents, circulation, tides, sea state, pile up, storm surges, tsunamis, air/sea interaction, surface winds, sea, lake and river ice.

POTENTIAL CONTRIBUTIONS OF SORTIE MODE

- Test-bed and observational platform for development and evaluation of instrumentation, such as: radar altimeters, scatterometers, precision multi-frequency imaging radar, imaging I.R. radiometer, bi-polarized multi-spectral imaging systems, laser altimeter, laser profilometer, laser scatterometer, and laser scanning photometer.

- To use man as an observer for correlation with the remote sensing, and to use his judgment to provide flexibility in the observing program and in the use of the equipment.

- To launch free-flying satellites for physical oceanography.

TITLE OF SORTIE MISSIONS

- Test-bed and observational platform for development and evaluation of instrumentation, such as:

  Radar altimeters
  Scatterometers
  Precision multi-frequency imaging radar
  Imaging I.R. radiometer
  Bi-polarized multi-spectral imaging systems
  Laser altimeter
  Laser profilometer
  Laser scatterometer
  Laser scanning photometer

- Deployment of free-flying satellites

FLIGHT SCHEDULE

1979 . 1 test-bed mission

1980 . 2 test-bed missions

1981 . 2 test-bed missions

1982 . launch SEASATS-2

1982 . 2 test-bed missions

1983 . 2 test-bed missions

1984 . 2 test-bed missions

1985 . 2 test-bed missions

1986 . First Operational Ocean Dynamics Satellite System

APPENDIX A

SOLID-EARTH DYNAMICS/EARTHQUAKE MECHANICS

APPENDIX A

Discipline Area: Solid-Earth Dynamics/Earthquake Mechanics

Sortie Title: Test-Bed Flight

Reasons for Sortie Mode: Availability of human operator, weight and power, massive data retrieval, plus rapid turnaround for retest if necessary make sortie mode the preferred mode.

Test-Bed Mission Requirements

- Length of flights: 1 week
- Orbit: 200 km, no special inclination
- Data requirements: 5 MHz
- Role and number of personnel in orbit: 1 experiment specialist
- Stabilization and pointing: 1 arc minute
- Power and thermal: 3 kw peak, 84 kw hours
- Weight of instruments: 500 kg
- EVA requirements: none
- Correlative measurements: ground truth
- General support equipment: video tape recorder
- Documentation requirements: no special requirements
- Special operating constraints: frequency international agreements
- Contamination requirements: no special requirements

Free Flight Satellites

- GEOPAUSE: Weight 1000 kg; diameter: 4 m; orbit: 30,000 km, polar circular.

- Vector Magnetometer Satellites: Weight: 150 kg; diameter: 1 meter folded, 4 meters deployed; orbits: 400 km, circular, separated by 4 hours local time.

- Magnetic Field Monitor Satellite: Weight: 200 kg; diameter: 1 meter folded, 4 meters deployed; orbit: 1000 - 2000 km, circular, inclinations 0 - 28°.

- Drag-Free Gravity Satellites: Weight: 3000 kg each; diameter 2 meters; orbit: 2 satellites at 200 km, separated by 200 km, polar, circular.

- Gravity Gradiometer Satellite: Weight: 3000 kg; diameter: 4 meters; orbit: 200 km, polar circular.

- Dense Laser Reflector Satellites: Weight: 100 kg; diameter 1/2 meter; orbits: 300 - 1000 km, different inclinations.

High Resolution Telescope for Tectonic Strain Field Measurements

- Requirement: Resolution and image-motion compensation to 5 - 10 cm for bright target.

- Implementation: Suggest modification of large space telescope design. Requires phase A design study.

APPENDIX B

OCEAN DYNAMICS

APPENDIX B

Discipline Area: Ocean Dynamics

Sortie Title: Test-Bed Flight

Reasons for Sortie Mode: Availability of human operator, weight and power, massive data retrieval, plus rapid turnaround for retest if necessary make sortie mode the preferred mode.

Test-Bed Mission

- Length: 1 week to 1 month
- Orbit:

  Inclination: at least 60°.
  Altitude: as low as possible
  Circular

- Data requirements: 15 MHz data link; on-board video tape recorder
- Role and number of personnel in orbit: 1 experiment specialist
- Stabilization and pointing:

  Stability: 1 arc second per second
  Pointing accuracy: 1 arc minute

- Power: 5 kw peak; 140 kw hours
- Weight of Instruments: 500 kg
- EVA requirements: None
- Correlative Measurements: Ground-truth measurements
- General support equipment: Video tape recorder
- Documentation Requirements: No special requirements
- Special Operating Constraints: No special requirements

- Contamination Requirements: No special requirements

Free Flight Satellites

- SEASAT 2: Weight: 1000 kg; orbit: 500 - 700 km, polar, circular.
- Operational Ocean Dynamics Satellite System: Characteristics to be determined. Probably several in orbit simultaneously.

Policies and Procedures which Must be Changed or Instituted to Fully Exploit the Shuttle Sortie Mode and Reduce the Cost of Research in Space.

- The experimenter should have only one administrative interface with the project, namely as the man in charge of the Sortie Lab with this as his full-time function.
- Wherever possible, backup experiments should be available as replacements in the event a scheduled experiment is not ready to fly. All backup experiments should be scheduled for flight.
- Where justifiable, provisions should be made to permit experimenters to operate their own equipment in space.

Brief Description of Estimated Magnitude of Sortie Mission User Community.

- Anticipated users include NASA, universities, other government agencies, industry, foreign experimenters.
- Expect about 25 experimenter teams, 200 individual investigators.

Recommended Approaches for Interfacing with the User Community.

- See Policies and Procedures above.
- Place abbreviated shuttle opportunity announcement in technical and scientific journals. Present short paper on shuttle capabilities at scientific and technical meetings.
- Prepare and distribute Shuttle User Handbook to interested individuals.

- Recommended emphasizing the experimenter team approach with the team being responsible for defining functions and roles of its members.

- NASA should establish a structure of discipline-oriented science and applications advisory boards to review and evaluate proposed experiments.

- Maximize the use of national and international scientific and technical societies to promote foreign participation in the shuttle program.

Future Actions Required to Implement Sortie Missions.

- Establish discipline areas for an in-depth study to define specific detailed missions objectives, instrumentation and data analysis requirements. This should be an iterative process which does not exclude new ideas that surface at a later date.

- Broadcast invitations to submit informal proposals.

- Based on the results of 1 and 2 above, establish phased SR&T or AAFE tasks to define experiments and demonstrate their capabilities. To make good on the advertised shuttle objectives will require a significant increase in the SR&T level at an early date, in each discipline area.

EARTH AND OCEAN PHYSICS

Solid Earth Dynamics/Earthquake Mechanisms	Ocean Dynamics
Tectonic Plate Structure and Motions	Currents
Fault Motions	Circulation
Polar Motion Variations	Tides
Earth Rotation Variations	Sea State
Solid-Earth Tides	Pile Up
Gravity Field	Storm Surges
Magnetic Field	Tsunamis
Volcanic and Geothermal Processes	Air/Sea Interaction
	Surface Winds
	Sea, Lake and River Ice

POTENTIAL CONTRIBUTIONS OF SORTIE MODE

Provide Test-Bed and Observational Platform for New Instrumentation Techniques

Use Man

- Observer
- Correlator
- Judgment
- Flexibility

Launch Free-Flying Satellites

- Demonstration of Techniques
- Operational Observations

SOLID EARTH INSTRUMENTATION TEST-BED

Instrumentation:

- Precision Imaging Multi-Frequency Radars
- FM Correlation Radar for Baseline Measurements
- Side-tone Ranging System
- Multi-Frequency Laser and Microwave Differential Refraction Experiment
- Laser Ranging/Altimeter Experiment

Mission Length: 1 week
Orbit: 200 km, circular, no special inclination
Data Rate: 5 MHz
Personnel: 1 experiment specialist
Stabilization and Pointing: 1 arc minute
Power: 3 kw peak, 84 kw hours
Weight of Instruments: 500 kg

OCEAN DYNAMICS INSTRUMENTATION TEST-BED

Instrumentation:

- Radar Altimeters
- Scatterometers
- Precision Multi-Frequency Imaging Radar
- Imaging I.R. Radiometer
- Bi-Polarized Multi-Spectral Imaging Systems
- Laser Altimeter
- Laser Profilometer
- Laser Scatterometer
- Laser Scanning Photometer

Mission Length: 1 week to 1 month
Orbit: Low, 60°, circular
Data Rate: 15 MHz; on-board video tape recorder
Personnel: 1 experiment specialist
Stabilization and Pointing: stability: 1 arc sec/sec; pointing: 1 arc minute
Power: 5 kw peak; 140 kw hour
Weight of Instruments: 500 kg

FREE FLIGHT SATELLITES

Solid Earth Dynamics

GEOPAUSE: Wt. 1000 kg; diameter: 4m; orbit: 30,000 km, polar circular.

Vector Magnetometer Satellites: Wt. 150 kg; diameter: 1 meter folded, 4 meters deployed; orbits: 400 km, circular, separated by 4 hours local time.

Magnetic Field Monitor Satellite: Wt. 200 kg; diameter: 1 meter folded, 4 meters deployed; orbit: 1000 - 2000 km, circular, inclinations 0 - 28°.

Drag-Free Gravity Satellites: Wt. 3000 kg each; diameter: 2 meters; orbit: 2 satellites at 200 km, separated by 200 km, polar, circular.

Gravity Gradiometer Satellite: Wt. 3000 kg; diameter: 4 meters; orbit: 200 km, polar circular.

Dense Laser Reflector Satellites: Wt. 100 kg; diameter: 1/2 meter; orbits: 300 - 1000 km, different inclinations.

Ocean Dynamics

SEASAT 2: Wt. 1000 kg; orbit: 500 - 700 km, polar, circular.

Operational Ocean Dynamics Satellite System: characteristics to be determined. Probably several in orbit simultaneously.

EARTH AND OCEAN PHYSICS FLIGHT SCHEDULE

Year	Solid Earth Missions	Ocean Dynamics Missions
1979	1 GEOPAUSE Satellite 1 pair Drag-Free Satellites 1 Test-Bed	1 Test-Bed
1980	1 Gravity Gradiometer Satellite 6 Dense Laser Reflector Satellites	2 Test-Beds
1981	3 Magnetometer Satellites 1 Magnetic Monitor Satellite	2 Test-Beds
1982	1 Test-Bed	1 SEASATS-2
1983	1 Test-Bed	2 Test-Beds
1984	1 Test-Bed	2 Test-Beds
1985	1 Test-Bed	2 Test-Beds
1986	3 Magnetometer Satellites 1 Magnetic Monitor Satellite	First Operational Ocean Dynamics Satellite

POLICIES AND PROCEDURES

1. One man in charge of sortie lab as full-time job.
2. He should be the only administrative interface with experimenter.
3. Back-up experiments should be available to fly on short notice.
4. All back-up experiments should be flown.
5. Where justifiable, provision should be made for experimenter to operate his equipment in space.

SORTIE MISSION USER COMMUNITY

Users: NASA, other government agencies, universities, industry, foreign experimenters.
Number: 25 experimenter teams, 200 individual investigators

INTERFACING WITH USER COMMUNITY

1. Reference policies and procedures
2. Announcements in technical and scientific journals. Papers on shuttle opportunities at national and international meetings.
3. Prepare and distribute Shuttle User Handbook to those interested.
4. Emphasize experimenter team approach.
5. Establish structure of discipline-oriented science and applications advisory boards to review and evaluate proposed experiments.
6. Use national and international societies to promote foreign participation.

FUTURE ACTIONS

1. In-depth studies of discipline areas to define specific mission objectives, instrumentation and data analysis requirements.
2. Broadcast invitations to submit informal proposals.
3. Based on 1 and 2 above, establish phased SR&T or AAFE tasks to define experiments and demonstrate capabilities. Significant increase in SR&T funding will be required.

REPORT OF THE
OCEANOGRAPHY WORK GROUP

CONTENTS

	Page
INTRODUCTION	5-1
MILESTONES FOR THE 1975-1985 PERIOD	5-12
ROLE OF SHUTTLE AND THE SORTIE MODE	5-13
MISSIONS	5-15
SIGNIFICANT COMMENTS ON MODE AND MISSION REQUIREMENTS	5-16
GENERAL PLANNING CONSIDERATIONS	5-17
APPENDIX A COMPILATION OF USER OCEANOGRAPHIC REQUIREMENTS THAT ARE FEASIBLE FOR REMOTE ACQUISITION	5-A-1
APPENDIX B TYPICAL INSTRUMENT PAYLOADS	5-B-1
APPENDIX C MISSION PARAMETERS	5-C-1

REPORT OF THE
OCEANOGRAPHY WORK GROUP

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INTRODUCTION

The water of the world represents a major component of the earth's ecological system. Knowledge of the oceanic and estuarine parameters, processes, and phenomena as a function of space and time is vital for man's understanding of the dynamic physical, chemical, and biological processes within these waters, the impact of man's activities on these processes, and the feedback responses of the oceanic processes on man and his environment. To understand, describe, predict, and manage his affairs in the marine environment, man must have information derived from measuring and monitoring oceanic parameters. Because of the vastness of the oceans of the world, economic and technological limitations impose restrictions on the quantity, variety, and timeliness of the information that can be acquired at any one time. Spaceborne remote sensors can play a role in meeting the needs for certain types of information about the spatial and time variations of some of the oceanic parameters such as surface temperature, sea state, sea ice, water color and oceanic circulation on a synoptic, repetitive and global basis.

GOALS AND OBJECTIVES

Within NASA, the goal of the oceanography discipline and its related activities is to establish the feasibility of, demonstrate the utility of, and develop prototype space operational systems to gather oceanographic data which will meet the needs of users in:

- Fisheries resources management
- Coastal zone activities

E

- Maritime activities
- Pollution monitoring, control and abatement

The attainment of this goal requires (1) an understanding of the various users' needs or requirements for information, (2) an assessment of NASA's space technology capabilities in terms of being able to meet the information needs or requirements, (3) utilization of appropriate space technology for the design and development of related remote sensor instruments, and (4) testing in the laboratory, in the field (e.g., on aircraft and balloons) and in space.

Information Needed

In these oceanographic areas, we have found certain information useful in helping us to cope with problems that arise.

Fisheries Resources Management

Locating fisheries by type and quantity and reliable forecasting of the movement of schooling fish are important to the conduct of more profitable fishing operations and effective management. Evidence has been accumulated to confirm that the distribution of fish resources can be correlated to sea surface temperature, chlorophyll concentration, and ocean currents, including upwelling, and that schooling fish may be located by detecting luminescence and fish oil slicks. By making available such information in the format of plots or bulletins, it should be possible to assist fishing operators to accomplish their tasks more efficiently as well as predict harvest yields more accurately.

Coastal Zone Activities

Coastal zone problem areas include a large variety and cover a wide range:

- Most of the important fisheries' resources are located within or adjacent to coastal zones, especially spawning areas.
- In recent years, new pressures have been brought to bear upon the coastal zone management by man's desire to take advantage of the recreational opportunities afforded him in terms of swimming, sports fishing, and boating.
- Industry has also turned more to the coastal zone area. The search for off-shore mineral, oil and gas resources, and the desire to construct off-shore oil terminals for handling deep draft tankers are two important examples.
- Maintenance of marshland ecology and water quality in the coastal zone (e.g., in light of harbor development and industrial and residential development) is becoming increasingly important.

- Salinity intrusion into fresh water supplies and agricultural lands can destroy their usefulness.

Many of the coastal charts now in use are outdated. Their usefulness in delineating navigational hazards and bathymetry has therefore been significantly reduced. Better baseline information on the coastal environment must be obtained and updated regularly to ensure better modeling, attain more accurate prediction, assess the overall impact on the environment and, in general, contribute to better coastal zone management. The kinds of information needed include: estuarine flushing rates, beach erosion rates, swells, tides, surf, storm surges, ocean currents, tidal currents, salinity (water and soil), ice conditions, biological chemical content, turbidity, bathymetry, vegetative cover, land use, squalls, surface films and surface winds.

Maritime Activities

The U.S. shipping industry is in competition with similar industries of other nations of the world. To be competitive, it must be able to move cargo quickly at a minimum of cost and with a minimum of damage enroute. Ship operations are costly, and any steps taken to minimize the enroute time of ships reflect in a cost saving. In routing ships, operators seek to take advantage of ocean currents wherever possible to reduce the enroute time and to avoid currents which can slow up the ship. Current tracks in the world's oceans are not static. Currents meander both in time and space. It is not possible to predict the meanders in advance. Ship operators, therefore, could derive benefits from near real-time information of the track of currents. The U.S. shipping industry is a user of weather information, basing its routing and scheduling of ships on weather as well as sea state forecasts. At the present time it is not possible to achieve the density of coverage required to develop reliable sea state forecasts by conventional data-acquisition techniques. The use of satellites equipped with remote sensors capable of obtaining broad area repetitive synoptic information of sea state conditions and ocean surface wind fields required for improved forecasts does have promise.

The U.S. Government has embarked upon a program to extend the Great Lakes shipping season which at the present time is restricted to the time the Lakes are free of ice. Remote sensing of the ice will provide valuable information on ice conditions (i.e., thickness, leads, pressure ridges) which will prove of value in the Coast Guard planning of operations to keep the ice open to the passage of ships. These techniques for ice monitoring will also prove valuable for shipping in arctic waters.

Thus, the information needed in this area includes sea ice, currents, sea state, shoals, surface winds, ice thickness and age, ship density, icebergs, thermocline depth, vertical density, salinity, bathymetry and underwater turbidity.

Pollution Monitoring, Control and Abatement

Water pollution has become a problem of great importance worldwide, in bodies of water as diverse as the farm pond and the open ocean. The world's oceans are the ultimate sink for all man-made and natural pollution. Only within the past few years has mankind the world over become aware of the buildup in pollution in the coastal regions as well as in the open oceans. It is necessary that systems which rapidly detect and measure water pollution be developed. It is anticipated that the present trend of accelerated pollution of the world's waters will continue into the 1980 time frame and that the development and application of instrumentation for the monitoring of specific pollutants from space will not only be desirable but mandatory.

Water pollutants can be classified into approximately five types from the standpoint of remote sensing: oil pollutants, nutrient wastes, suspended sediment, chemical and toxic wastes (that produce a detectable effect), and thermal effluents. The observables that provide either direct or indirect clues to the presence of these pollutants are variations or anomalies in water color, surface temperature, surface roughness, emissivity, and polarization of surface-reflected sunlight.

MEASUREMENTS NEEDED

Basic Oceanographic Parameters

As we study the nature of the information needed for the management of oceanographic problems, it is clear that overlapping types of measurements are needed (i.e., measurements that could be applied to more than one area.)

These measurement needs, considered by the working group in relation to the problem areas, are summarized in Table 5-1. User requirements to various depths of detail have been identified in other studies, one of these being by Vest and Claggett of the Computer Science Corporation. Appendix A is a reproduction of data requirements that they reported to U.S. NAVOCEANO on Contract No. 62306-70-C-0149.

Applicable Instrumentation

Experience in remote sensing to date has indicated rather clearly which spectral bands (and the instruments sensitive to these spectral bands) can provide

information, sometimes rather quantitative, about these basic oceanographic parameters. Table 5-2 provides such a listing. It shows the application possibilities--as identified by numerical code number--for each of the several instruments. The fact that there is duplication does not necessarily mean that we have redundant information. Research is underway and more needs to be conducted to assess the relative contribution of each instrument. We expect to find that the information is, in fact, supportive and complementary. More specific information about instrument possibilities will be given below.

Included in the table are two entries which require some additional explanation--data collection and atmospheric package. By its very nature, information about the sea derived by remote sensing techniques is limited to the surface layer of the ocean. However, vertical structure of temperature and salinity is an important oceanographic measurement and fundamental to the proper management of all of the problem areas. In order to acquire this kind of information in the open ocean, ship or buoy systems with in situ measuring instruments will be needed. Data collection systems involving satellites developed in the U.S. meteorological program, or the French EOLE satellite, or Earth Resources Technology Satellite (ERTS) could be used to relay the data acquired locally to a central receiving station for processing and distribution.

Mentioned, but not discussed here, is an atmospheric package which through the use of meteorological sensors will give information on the related atmospheric parameters needed for the support of the oceanographic user community.

CHARACTERISTICS OF INSTRUMENT POSSIBILITIES

In this section we will discuss in greater detail properties of possible instruments* in the various spectral bands. In discussing these instruments, we have kept in mind their possible application to shuttle-launched oceanographic missions.

Ocean Surface Spectroradiometer (OSS)

An OSS instrument will be used to map ocean color in a number of selected spectral intervals (primarily visible). Selection of the exact intervals will be made after analysis of the data obtained during the NASA CV-990 Ocean Color Expedition of 1972. Though this analysis is not yet complete, some parameters of the OSS can be estimated at this time.

*Additional details about the instruments discussed will be found in Appendix B.

Table 5-1

Identification of Problem Areas and Measurements

	Problem Areas	Measurements
Fisheries	Location and Movement Type Quantity Ecological Factors	Temp. Gradients Chlorophyll (Color) Sediment Salinity Tides Currents Luminescence Fish Oil Slicks Sound Upwelling
Coastal Zone Activities	Erosion; Recreation; Harbors; Offshore Activities; Tide Excursions; Deep Sea Ports; Charting, Mapping; Nutrients; Saline Intrusion	Sediments; Sea State; Shoals; Salinity; Tides; Surface Winds; Squalls, Chlorophyll; Land Imagery; Temperature; Surface Films; Turbidity; Bathymetry
Pollution	Oil· ·vage; Industrial Wastes; Nutrient Waste; Thermal Effluents; Sediments	Currents; Temperatures; Color; Salinity; Surface Roughness; Pollutants; Surface Films
Maritime Activities	Ship Routing; Hazard Avoidance; Offshore Activities (mining, drilling)	Sea Ice; Currents; Sea State; Shoals; Surface Winds; Ice Thickness & Age; Ship Density; Ice Bergs; Thermocline Depth; Vertical Density and Temperature; Salinity; Bathymetry; Underwater Turbidity

Table 5-2

Instrumentation Possibilities

Measurements	Instrumentation	Application
1. Surface Temperature 2. Temperature Gradient 3. Vertical Structure (temp. & salinity) 4. Luminescence 5. Surface Films 6. Water Color (Chlorophyll, turbidity, sediment) 7. Salinity 8. Radiation Budget 9. Surface Roughness 10. Ice Thickness 11. Sea Ice 12. Ice Bergs 13. Sea State 14. Currents & Tides 15. Bathymetry 16. Land Imagery 17. Shoals 18. Pollutants 19. Surface Winds 20. Squalls	Film Camera Multi-Spectral Scanner	4, 5, 6, 9, 11, 12, 12, 14, 15, 16, 17, 18, 20
	Laser	4, 5, 9, 13, 15, 18
	Polarimeter	5, 9, 13, 17, 18
	Multi-Spectral Imager (near IR)	5, 11, 12, 16
	Multi-Spectral Imager (thermal IR)	1, 2, 8, 14, 18
	Multi-Spectral Microwave (passive) Radiometer 1 GHz — 60 GHz	1, 2, 5, (7), 9, 10, 11, 12, 13, 14, 17, 18, 19
	Multi-Spectral (active) Imager 300 MHz — 30 GHz	5, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20
	Data Collection	3 and others
	Atmospheric Package	1, 2, 8, 19, 20

The OSS will measure relfected solar radiation from the ocean-atmosphere system in approximately ten spectral intervals from 400 to 1100 nanometers. Eight of these channels will measure ocean color contaminated by atmospheric scattering. Two channels, one in the ultraviolet and one in the near infrared, will measure atmospheric scatter only. The results of the measurements in these two channels will be utilized to remove some of the effects of atmospheric scatter from the other eight.

High altitude aircraft measurements indicate that a signal-to-noise ratio of at least 400 to 1 will be required in order to discriminate to 1 part in 10 chlorophyl concentrations ranging from 0.01 to 3.0 mg/m^3, the normal range found in the open oceans. This requirement, together with user requirements for a 2x2 km spatial resolution, will be met with minimum spectral bandwidths of 15 to 20 nanometers per channel in the eight channels devoted to ocean color measurement. The two channels devoted to atmospheric scatter measurements will also serve as cloud detectors and heavy haze detectors to provide an indication when the data are two heavily contaminated with particulate scattered energy to be of use.

Instrument output will be a telemetered digital bit stream that can be reduced, either by a NASA facility or by users. Maps of such parameters as chlorophyl concentration or sediment load can be made. Since the data rate is modest, it may be desirable to provide an APT mode for some of the channels so that users, such as fishing vessels, could collect real-time data in their area of interest.

Sea Surface Temperature Infrared Radiometer (SSTIR)

The infrared radiometer will be configured to sense reflected-solar and terrestrially-emitted radiation in five spectral intervals. These five channels with the function of each are as follows:

Wavelengths of Spectral Channels (Approximate) (μm)	Parameter	Measurement
(1) 10.5-11.5	IR window	Sea-surface temperature from multispectral analysis in clear skies (In addition, for channel 1: radiation budget, correlative imagery for other measurements).
(2) 8.85-9.35	Water-vapor continuum	
(3) 6.5-7.0	Water-vapor absorption	Thin-cirrus identification, multispectral analysis.
(4) 3.6-4.1	IR window	Cloud (night), multispectral analysis.
(5) 0.2-3.5	Solar radiation	Cloud (day) multispectral analysis, radiation budget, correlative imagery for other measurements.

The use of the five channels will provide an appreciable increase in accuracy. The long wavelength channel, 10.5 to 11.5 micrometers, has been considered the best day and night "window" for thermal measurements, but there is still considerable water vapor absorption in this spectral interval. The 8.85 to 9.35 micrometers channel is in an area of slightly greater water vapor absorption, and its measurement of equivalent black body temperature will be employed, in an algorithm, to correct that of the 10.5 to 11.5 micrometer channel.

The other three channels serve to provide a night and day cloud identification capability to determine the degree of cloud contamination of the long wavelength measurements. The 3.6 to 4.1 micrometer channel can also serve to supplement the sea-surface-temperature determination at night when no clouds are present.

In order to meet the user requirements for spatial resolution and global coverage, the sensor will have an instantaneous field of view at the surface of 2x2 km and a swath width of 2870 km (1550 n.mi.). This swath width, coupled with a 1000 km (539 n.mi.) sun-synchronous, high-inclination orbit will provide the required daily coverage.

The output of the SSTIR will be a digital bit stream that will be processed to a sea-surface-temperature map for delivery to users. It is also anticipated that the modest data rate required will allow an APT mode where users such as ships can receive one channel directly and monitor such variables as ocean current location and motion where thermal contrast is more important than absolute temperature accuracy.

Radar (Active Microwave)

The radar measures the surface backscattering properties. The backscattering properties of the ocean are a function of sea state, ocean wave configuration, and the dielectric properties. Most of the backscatter results from surface features with radii of curvature less than one-tenth of a wavelength. Therefore, it is essential to provide as wide a range of wavelengths as reasonable in order to ensure that the acquired data have the maximum information and that the measurements cover the full spectrum of sea state conditions or sea ice conditions.

In the imaging mode, a radar antenna needs to be about 5 m^2 in size (5m x 1m is typical for L-Band) and needs to be held within 1 degree in pointing by an attitude control system. The radar itself will pull the position control to within 0.01 degrees electronically. The antenna will most likely be a section of a parabola (not a phased array).

The image data is acquired in the form of range-doppler information which can be recorded on film or telemetered to a ground station or both. Conversion of

the data to imagery does not reduce the bit rate and tends to unnecessarily complicate the spacecraft system. The acquisition word rates (burst rates) can be as great as 25 megawords/sec.; the average bit rates are on the order of 1 to 6 megabits/sec. A data storage system of 3.6×10^9 bits (e.g., ERTS tape recorder) is adequate for 100 meter resolution, 100 km swath width all around the earth. A dump rate of 6 megabits/sec. would clear the record in 10 minutes-or in one nominal pass over a ground station.

The radar bandwidths are generally wide, and EMI and RFI are usually serious problems. The radar sensor is a multispectral imaging system and will cover the frequency range of 300 MHz to 35 GHz in about 6 bands.

The imaging radar will provide information pertaining to ocean wave patterns (open ocean or harbors), coastal estuary effluents, shoal locations, schooling fish, and surface wind patterns. Most important is the fact that the data acquired will not be restricted by cloud cover or solar illumination. An additional major use of the radar imagery will be to aid in the near real-time determination of sea state conditions for ship routing.

In the altimeter mode of operation, a radar measures the altitude or distance between the spacecraft and the ocean surface, in addition to information concerning the surface backscattering properties. The altitude measurements, or rather, changes in the altitude measurements, will be primarily a function of the orbit of the spacecraft and the topography of the ocean surface. *

Providing the altimeter has sufficient resolution and considering the orbit to represent a stable reference to reasonable lengths of time, all topography features which exceed 0.1m and are not spatially averaged to zero will be resolved by the altimeter. The absolute altitude furnished by the altimeter can provide excellent information for the calibration of onboard camera systems.

*Dynamic oceanographic parameters influencing the topography of the ocean surface and typical magnitudes are listed below:

Parameter	Magnitude (Meters)
Sea State	0-30
Tides	0-5.0 (near shore)
Currents	0.5-2 m/sec.
Barometric pressure effects	0.1 nominal 5.0 maximum
Tsunamis	0.5 (mid-ocean)
Storm Surges	15 max.

Radiometer (Passive Microwave)

A microwave radiometer measures the brightness temperature of the surface which is related to the emissivity and true temperature of the surface and immediate subsurface. The brightness temperature contains a maximum of information when the surface areal resolution is good and a wide range of frequency bands are covered. Consequently, the instrument may have a large antenna with a mechanism for spatial scanning and several receiver horns to accommodate the various frequency bands. Phased arrays for rapid scanning and single frequency bands may also be used.

The radiometer is a wide-band receiver and as such will be very sensitive to EMI or RFI. Special coordination with other spacecraft systems will be necessary if the radiometers are to operate successfully. The sensor is, basically a multispectral imaging system covering the frequency range of 1 GHz to 95 GHz in about 11 frequency bands, each about 250 MHz wide.

A large antenna, up to 100 meters in diameter, is required and will probably have to be assembled in space. The beam width of a 100 meter dish at 1.000 GHz would be about 0.005 radians and provides an areal resolution of 500 meters at an altitude of 100 km, nadir-viewing; it will be somewhat larger for conical scanning. The use of the microwave radiometer for oceanographic studies is primarily related to surface effects.

Advanced Instrumentation

The above instrumentations are essentially extrapolations from known developed instruments, some of which are being planned for flight. Prior to the 1980's, through AAFE and SR&T efforts, there will be various additional instrumentation concepts with potential application to spaceborne oceanographic observations. These instruments could be imaging or nonimaging, active or passive. A partial list with brief descriptions of instrumentation currently under early development follows:

- Derivative Spectrometer — An instrument which provides as its output a derivative with respect to wavelength of the spectral radiance from a source. The method has potential to reduce the effects of slowly varying spectral functions of atmospheric and hydrosol scattering, while enhancing and separating absorption bands. Applications include chlorophyll, turbidity, and pollutants.

- Laser Fluorimeter/Bathymeter — A pulsed laser with a high speed detection system for viewing either the return of the transmitted pulse or the induced fluorescence emission from the water surface or water body. By using a pulsed blue-green laser and viewing the return from the surface of the water and the return from the water bottom, a remote measurement of water depth can be performed. By using an ultraviolet pulsed laser, it is possible to excite fluorescence in oil films, chlorophyll a, and rhodamine B dye. In this application, the detection system is filtered to pass only the spectral region associated with the fluorescence and to block the wavelength of the excitation pulse. Applications include surface films, chlorophyll, turbidity, surface roughness, vertical structure, bathymetry and pollutants.

- Imaging Polarimeter — An imaging instrument capable of measuring the intensities of the two perpendicularly-polarized components of radiation reflected and backscattered from a water body. Measurements at Brewster's angle can be used to measure radiation primarily backscattered from the water body. Measurement of the difference in intensity between the two polarized components yields information representative of water surface characteristics. Applications include turbidity, pollutants, surface films, and surface roughness.

- Differential Imager — An instrument consisting of two imaging channels having different wavelengths or polarization sensitivities. In real-time one image is subtracted from another such that only spectral or polarization differences between the two images are recorded or presented to the experimenter on a viewing monitor. Information common to both channels is rejected, and only information differences are thus displayed. Applications include chlorophyll, water color, surface films, and surface roughness.

- High Resolution Pointable Imager — A multichannel, limited-field-of-view imager capable of being pointed off-nadir. Requirements exist for a remote sensor of coastal zone features at a resolution better than that required in the broad oceans. The monitoring of rivers and estuaries as well as coastal land use requires a spatial resolution of approximately 20 meters. Four channels in the visible and near IR (similar to those of the ERTS A Multispectral Scanner) and a swath width of 20-35 km would result in a data rate of about 30 Mb/s. One promising approach to such an instrument is that of a solid-state array multispectral-line-scan ("pushbroom") imager.

MILESTONES FOR THE 1975-1985 PERIOD

In order to achieve the oceanography discipline area goals, several key research and development milestones must be met. These milestones are:

- Develop remote sensors and appropriate data processing and display systems as well as methods which will best meet the information needs of the users.

- Conduct experiments leading to the verification of correlation of remote sensor system signatures and data outputs with oceanographic parameters (i.e., sea state, sea ice, sea surface temperature, water color) and with water quality (i.e., pollution, turbidity, sedimentation, chlorophyl concentration, and salinity).

- Conduct engineering tests of the remote sensor systems from space platforms to verify performance and reliability and to determine the optimum mix of instruments for operational systems.

- Conduct experiments directed toward a pre-operational demonstration of the utility of remote surveys of the coastal zone or open ocean from space in providing information to facilitate the solution of user problems or the initiation of management or operation decisions.

Some operational capability will be existing prior to the 1980's for some of the oceanographic applications. The effort in the late 70's and 80's will build on that capability. Yet much will remain to be done, and meeting these milestones will extend the capabilities to meet the user needs.

ROLE OF SHUTTLE AND THE SORTIE MODE

The shuttle system and especially the sortie mode can be responsive to the oceanography milestones for the decade of the 1980's. Two broad roles for shuttle utilization are:

- R and D — where the development of advanced instrumentation and the intercomparison of sensor systems would be accomplished, and

- Operational — where (1) unmanned satellites would be deployed into orbit, (2) large components or subsystems (such as microwave antenna) would be assembled, and (3) special short-time, high-resolution, limited-coverage missions would be performed.

These two uses are discussed at greater length in the sections which follow.

R AND D MODE

In the development of advanced instrumentation, the sortie lab will afford experimenters a versatility heretofore unavailable in space. Intercomparisons of sensor systems will not only verify new instruments and techniques but will also,

and more importantly, demonstrat the mix of instrumentation required to serve most effectively the various users. The tasks associated with the microwave R&D are especially critical in that much of required instrumentation cannot be evaluated except in space. The antenna for the passive microwave radiometer is such an example. The initial R&D here may be simply in the techniques for assembly and in the evaluation of the mechanical and thermal effects on the electrical characteristics of the antenna in space. Evaluations may also be required concerning antenna configurations (e.g., an array of parabolas in a mills cross or a single parabola with multiple receiver horns.) While design studies will indicate much to answer the question, it will be only in the space environment that the proof of performance can be attained.

OPERATIONAL

Deployment of Simple Unmanned Satellites

A basic role of the sortie mode in operational space oceanography activities is the deployment of unmanned satellites in orbit. This will include the deployment of moderate size satellites equipped initially with passive sensors operating in the visible and IR regions of the spectrum. These satellites will generally require operational altitudes of 400-600 n. miles. These satellites might be launched into these orbits with shuttle or non-shuttle propulsion systems. This requires further study.

Deployment of Large Antenna Systems

A variation on the type of deployment described above would utilize some of the more unique characteristics of the shuttle system. It would involve oceanographic satellites equipped with microwave systems employing large antennas, as well as visible and infrared sensors. These satellites would be launched into "shuttle altitude" orbits where the large antenna would be deployed and assembled with manned support in an EVA mode. The payload, with antennas deployed, would then be propelled into the required operational orbits of 300 to 600 nautical miles. In certain cases, the shuttle would be required to rendezvous with antennas left in orbit from previous missions, couple them to automated satellites, and then launch them into higher orbit for operational activities.

Short Time, High-Resolution Limited Coverage

Many of oceanographic parameters are quite dynamic requiring repeti cover-age of high frequency, e.g., daily. Howeve. certain of the coast - parameters are less dynamic, and annual or semi-annual coverage would be adequate.

For these, a requirement exists for relatively high resolution. It is believed that these types of missions can be accomplished by the shuttle mode with orbits particularly designed to provide optimum geographic coverage. The relatively low operating orbits of the shuttle will enhance the resolution capabilities of the sensors, which may be the same as those used on other operational missions. In this mode, the payload would be an integral part of the shuttle and would be returned to earth for future operational mission use.

MISSIONS

In this section we will consider a number of specific oceanographic missions using the shuttle. They will be patterned after the previous section and will consider R&D and operational missions in turn.

R&D MISSIONS

In order to conduct the R&D activities described earlier, a variety of short shuttle sortie missions will be required. A set of four missions conducted annually will allow a range of test conditions believed adequate for R&D purposes. Within an annual cycle, a set of equipment may or may not change. The four types of oceanography missions are listed below, with more detailed parameters of these missions presented in Appendix C.

- OR&D 1. — A sun-synchronous orbit to achieve repetitive constant illumination conditions and world-wide coverage

- OR&D 2. — A high-inclination, near-polar orbit to achieve world-wide coverage and a variation of sun-related parameters.

- OR&D 3. — A medium inclination orbit tailored to support special areas of study such as the coastal zones.

- OR&D 4. — A low inclination orbit primarily for instrumentation development--For example, an equatorial orbit will provide many repetitive ground tracks over the same ground truth areas and as such would permit a good determination of the stability of instruments.

OPERATIONAL MISSIONS

In order to conduct the operational oceanographic activities described earlier, several types of shuttle missions will be required. Two types of oceanography missions are as follows:

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- Global ocean monitoring will require the launch of one or more automated satellites annually into high-inclination, high-altitude orbits. These satellites will initially be equipped with visible and infrared sensors with moderate resolution and wide swath capabilities. Later satellites will incorporate large microwave antennas and involve crew EVA for antenna assembly in orbit.

- Coastal zone updating will require one to two shuttle missions yearly into medium-inclination, low-altitude orbits. The payloads for these missions will include relatively high resolution instruments with moderate swath capabilities, and these missions will be conducted completely with the shuttle and its reusable payload.

SCHEDULE OF FLIGHTS

- R&D Flights — 4 per year starting in 1980.

- Operational — One automated satellite per year with propulsion capability using shuttle as a launch platform.

  One to two coastal zone shuttle missions starting in 1980 using the shuttle sortie as the payload carrier.

SIGNIFICANT COMMENTS ON MODE AND MISSION REQUIREMENTS

This initial study brought several points to focus which might be viewed as initial or tentative conclusions concerning the shuttle mode and mission requirements for oceanography discipline activities. These comments are highlighted because they have direct impact on considerations of the shuttle operation or the sortie lab.

- Microwave antennas may be too large for the space shuttle envelope. While design studies need to be made on the methods best suited for their assembly and deployment in space, it is almost certain that EVA will be required. Because of the size of some of these antennas, it is anticipated that once assembled they will be left in orbit for reuse. Thus, the shuttle would be used to rendezvous with the antenna and to retrieve and replace different spacecraft for operation therewith.

- High inclination orbits are generally preferred. R&D and operational oceanographic missions must focus on the global oceans, including the polar ice regions. It is recognized that for the sortie lab missions, this will result in a weight penalty for the experiments. The seriousness of this penalty upon the experiment instrumentation remains to be investigated.

- Operational global-ocean-monitoring satellites will require high-altitude (400-600 n. mi.) as well as high-inclination orbits. Many will be sun-synchronous to assure minimal variation of solar-illumination angles. The need exists for auxiliary propulsion to attain these orbits.

- Seven-day flights are considered minimal. The time to repeat the overflight of given test sites and other specific areas of investigations are orbit restrained. It is recommended, therefore, that longer-duration missions be planned for as early in the program as possible.

- Downward (nadir) looking windows for use by the experimenters are required. Their use will permit real-time decisions on the part of the experimenter in conduct of the experiment and in data acquisition. Standard mounting provisions should also be made at these windows for experimenter equipment use.

- The telemetry mode as a major means for data return is mandatory. Oftentimes not all of the principal experimenters will be aboard the sortie lab, and in order for them to participate fully in the experiment, they will require considerably more data to the ground than is presently envisioned. A telemetry capability comparable to ERTS seems reasonable.

- Detailed definition of the contamination expected in the sortie lab-pallet area is required immediately. This will define not only the protection required for sensing devices but also the operational modes and analyses required for accomplishing experiment objectives.

GENERAL PLANNING CONSIDERATIONS

POLICY AND PROCEDURE MATTERS

The following points are related to matters of policy and procedures which must be considered to exploit more fully the shuttle sortie mode and the oceanographic applications:

- Integrated Experiment Development Program — The program offices should establish focal points to maintain contact throughout the development of experiments leading to space flight demonstrations using the shuttle sortie modes. This focus would ensure that discipline objectives are being fostered and integrated with other discipline activities and instrumentation as required.

- Lead Center — A lead center for oceanography should be established to assist the program office in the management of the development of vital oceanographic experiments.

- Ground Truth Coordination — Arrangements must be made on a more formal basis to ensure the existence of the ground truth information required for the verification of remote sensing of oceanographic parameters during R&D missions.

- Experimenter-Oriented Procedures — The procedures required of the experimenter for shuttle sortie missions should be oriented so as to ensure the full and direct involvement of the experimenter in experiment preparation, in-flight participation, operation and maintenance of the experiment, and data analysis and reporting. Required documentation should be kept to a minimum. The approach should be to start in a simple manner (CV-990 analog) and become more complex only if it becomes absolutely necessary. A single point of contact for the experimenter should be established, and it is suggested that this be the mission specialist for the sortie lab to which the experiment is assigned.

- Sortie Lab Description Document — A regularly updated single document should be available to experimenters which describes the characteristics of the sortie lab. An excellent beginning in this respect is Sortie Lab System Utilization Characteristics, dated June 27, 1972, by the Preliminary Design Office, Program Development, MSFC.

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

The potential user community for the Oceanography discipline is quite extensive. A listing at broad organizational levels is given below. A more detailed listing of agencies and areas of responsibility is given in item 6 of References below.

- Federal Government — Department of Commerce, Department of the Interior, Department of Transportation, Department of State, Department of Defense, Environmental Protection Agency, National Science Foundation, Smithsonian Institution, Atomic Energy Commission, National Academy of Science, National Academy of Engineering.

- State Governments — Atlantic States Marine Fisheries Commission, Gulf States Marine Fisheries Commission, Pacific States Marine Fisheries Commission. River Basin Commissions.

- Industries — Fishing, Shipping.

- International Organizations — United Nations (Committees, Commissions, Associations, Centers, Councils, Programs, etc.).

- Others — (Examples: International Field Year for the Great Lakes; International Ice Patrol; World Oceanic Organization)

USER COMMUNITY INTERFACE

The National Oceanic and Atmospheric Administration (NOAA), Department of Commerce, is the focal point within the U.S. Government for the oceanographic discipline and as such could very well serve as the focal point for the entire oceanographic user community. NASA should involve NOAA immediately for coordinating the activities necessary to bring the user community into the knowledge and understanding of the opportunities of the shuttle sortie missions.

INSTRUMENT TEAMS

It is evident that instrumentation proposed for oceanographic missions has potential for utilization by other disciplines. The formation of an instrument team, responsible for the development of a specific instrument to meet the needs of several disciplines, is recommended. For example, the multispectral radar (active microwave) imager described in this report is of interest to the earth resources as well as to the earth and ocean physics disciplines.

NEED FOR SHUTTLE OFFICE RESPONSE

The Oceanography Working Group supports the idea of active dialogue and interaction with the appropriate shuttle and sotie lab representatives at the working group level. An early response from the shuttle office concerning this present report is required to enable our working group to take the next steps.

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7. Earth Observatory Satellite (EOS) Definition Phase Report, Vol. 1, NASA-GSFC, August 1971.

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APPENDIX A

COMPILATION OF USER OCEANOGRAPHIC REQUIREMENTS THAT ARE FEASIBLE FOR REMOTE ACQUISITION

Table 5-A-1
Compilation of User Oceanographic Requirements that are Feasible for Remote Acquisition*

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
FISHERIES	• Location of areas suitable or unsuitable for fish habitation • Location of fish schools • Potential sea state conditions in operating areas	Sea Surface Temperature (Thermal Gradients)	Local	1-4 per day	Daily	Chart, Facsimile, Radio	1 per km^2	-5° to -35°C	500m	NA	0.5° to 1.0°C	Parameter range for various fisheries falls within the bounds given but usually does not include the whole range. For Calif. coast -12° to 27°C is adequate.
			Regional (coastal)	1-4 per day	Daily	Chart, Facsimile, Radio	1 per km^2 to 1 per $10km^2$	-5° to +35°C	500m to 1000m	NA	0.5°C to 1.0°C	Pearcy in Oregon coast studies found SST fluctuations to be rapid and complicated. Thus his stated requirements are for 100m and up to 0.1°C resolutions.
			Regional	Weekly	Weekly	Mag. Tape, Chart, Tabulation, Facsimile	1-2 per $400km^2$	-5° to +35°C	10km	NA	1.0°C	In general, charts with 1.0° needed at scales of 1:100,000 to 1:1,000,000 every week (132)
		Chlorophyll	Regional (coastal)	Weekly	Weekly	Map, Chart	1 per km^2	0.1 to 1.0 mg/m^3	100-1000m	0.01μ	1.0°C	Chlorophyll concentration should be contoured every 0.2 mg/m^3 with an accuracy of 0.1 mg/m^3. Absorption peak of chlorophyll is 0.67μ. Little data acquired presently. Parameters to measure is color.
		Sea State • Wave Height • Wave Length • Wave Period • Wave Direction	Regional (coastal)	Daily	Daily	Facsimile, Charts (on Board, Vessel), Radio	Regional (coastal) 1 per 20 km^2 Regional ~1 per $100km^2$	• 0-30m • 0-300m • 1 40sec • 0°-360°	• 0.5-2m • 25m • 1-5sec • 2°-5°	NA	NA	Japanese tuna vessels presently have on-board facsimile recording for sea state information. Information should include historical as well as present data
		Pollution (Various Pollutants Included)	Local	2-4 per day	Daily	Mag. Tape, Map	Not Specified	Various - (depending on pollutant)	30m	0.01μ	0.5°C	Most requirements have yet to be adequately defined. Greatest density of data is required from near in coastal areas - bays, estuaries, harbors, marinas, and around offshore oil drilling platforms on a fairly repetitive basis.
			Regional (coastal)	Daily	Daily	Mag. Tape, Map	Not Specified	Various - (depending on pollutant)	60m	0.01μ	1.0°C	
		Currents • Size and Location • Direction • Velocity	Regional	Daily	Daily	Map, Chart	1 per km^2 to 1 per $10km^2$	• 100m-2km • 0-360° • 0.5-10 knots	• 500m • 5° • 1 knot	0.01μ	1°C	Current boundaries (fronts) are the areas of interest and may be delineated by color, temperature, or other anomalies.
			Regional Global	Weekly	Weekly	Map, Chart	1 per 500 km^2	• up to 50km • 0-360° • 0.5-10 knots	• 1000m • 5° • 2 knots	0.01μ	1°C	

*See Reference (1) under References.

Table 5-A-1 (Cont'd.)

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
(Cont'd)	(Cont'd)	Salinity	Local (coastal)	Daily	Daily	Charts, Maps	Not Specified	0.01-40 parts per thousand	See Comments	NA	NA	Observational accuracy of 10% in coastal zone and 1% in estuaries.
		Upwelling	Regional (coastal)	Daily	Daily	Map, Chart	1 per $10km^2$	500m to 1000m	500m	0.01μ	1°C	Requirements are comparable to those for currents
			Regional	Weekly	Weekly	Map, Chart	1 per $500km^2$	Not Specified	1000m	0.01μ	1°C	
		Ocean Color	Local	Daily	Daily	Map, Chart, Graph, Photo	1 per km^2	NA	100m	0.01μ	NA	Information on water color is important for the measurement of a number of phenomena. Information on color can be obtained either in an image format (camera) or spectral format (spectrometer, spectrophotometer). Both techniques have certain advantages. See Section 4.10.
			Regional (coastal)	Daily	Daily	Map, Chart, Photo	1 per $10km^2$	NA	100m	0.01μ	NA	
			Regional	Every 5 days	Every 5 days	Map, Chart, Photo	1 per $500km^2$	NA	1000m	0.01μ	NA	
		Fish Schools • Photography • Luminescence • Spectral Detection • Slicks	Regional (coastal)	1-4 a day in area of fishing activity	Near Realtime	Facsimile, Radio	Not Specified	10m to 7km	15-30m	150Å	NA	The range of light emitted by low and high concentrations of luminescing organisms has not been specified. Fish schools have a wide size range.
MARINE TRANSPORTATION	• Potential sea state conditions in operating area • Optimum routing • Location and position of shoal areas	Sea State • Wave Height • Wave Length • Wave Direction	Regional (coastal)	2-4 per day	Near Realtime	Facsimile, Radio	1 per $20km^2$	• ~30m • 0-300m • 1-40sec • 0-360°	• 0.5-2m • 25m • 1-5sec • 2°-5°	NA	NA	Because of density of traffic more frequent and more accurate information required in certain regional areas.
			Global	1-2 per day	Near Realtime	Facsimile, Radio	1 per $100km^2$	• ~30m • 0-300m • 1-40sec • 0-360°	• 0.5-2m • 25m • 1-5sec • 2°-5°	NA	NA	Most requirements for height resolution were about 2 meters, small craft require sea state information associated with >10 knot winds. Travelers Research Report (4) specified 10° for coastal and 20° for open ocean wave direction.
		Currents • Extent • Velocity • Direction	Regional (coastal)	Daily	Daily	Facsimile, Charts, Reports	1 per km^2 to 1 per $10km^2$	• 100m-25km • 0.5-10kt • 0-360°	• 500m • 1kt • 3°	0.01μ	1°C	These requirements were derived from various reports. Individual users did not specify requirements other than that they would like information on ocean currents.
			Global	Weekly	Weekly	Facsimile, Charts, Reports	1 per 500 km^2	• Up to 50 km • 0.5-10kt • 0-360°	• 1000m • 2kt • 5°	0.01μ	1°C	
		Icebergs	Regional	Semi-Weekly to Daily	Within 12 hours	Facsimile, Charts, Radio, etc.		15m and up.	15-20m	NA	1°-2°C	Location of icebergs to accuracy of ±8km. Requirements specified are from U.S. Coast Guard.

Table 5-A-1 (Cont'd.)

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
(Cont'd)	(Cont'd)	Sea Ice • Extent • Thickness • Type	Regional	Daily-Weekly	Within 12 hours	Facsimile Charts, Radio, etc.		• NA • 0-20 • NA	• 30-100m • <1m • 30-100m	NA	• 1.0-2.0°C • NA • NA	For long-range ice forecasting, kilometer resolution is adequate. Sea ice thickness required for such shipping routes as Great Lakes, Northwest Passage, etc.
		Bathymetry	Global (coastal) and shoal areas	NA	NA	Charts, Maps		~0.200m	<2m near shore 5m farther from shore Horizontal ~30m	0.02-	NA	See chart on Bathymetry. Safe surface navigation requires that all ocean areas with charted depths less than 30m that are in doubt be verified.
OCEAN INDUSTRY • Oil/gas drilling • Construction • Recreation • Submersible operations • Mineral exploration and exploitation • Cable laying	• Potential sea state conditions in operating areas • Water depth in operating areas • Bottom characteristics in operating areas • Pollution in operating and recreation areas	Sea State • Wave Height • Wave Length • Wave Period • Wave Direction	Local	Every 3 to 6 hours	Realtime	Facsimile, Teletype, Computer Terminal	Not Specified	• 0-30m • 0-300m • 1-40sec • 0-360°	• 0.3m • NA • NA • 2°-5°	NA	NA	Weather forecasts good for up to 2 weeks are required by many marine industry users. Wave height is the most requested information.
			Regional	Daily	6-12 hours	Facsimile, Teletype, Computer Terminal	Not Specified	• 0-30m • 0-300m • 1-40sec • 0-360°	• 0.3-1m • NA • NA • 2°-5°	NA	NA	
		Pollution	Local	Daily	Daily	Radio, Charts, Photos	Not Specified	Various-depending on pollutant	10-20m	To be Determined	1°C	Recreation industry is eminently interested in pollution although they are not sure of their requirements. Requirements specified here are those of the scientific community.
			Regional	Weekly	Weekly	Radio, Charts, Photos	Not Specified	Various-depending on pollutant	10-20m	To be Determined	1°C	
		Water Depth	Global (coastal and shoal areas)	NA	NA	Charts, Maps	Not Specified	0-200m	Vertical-<2m near shore, <5m farther from shore. Horizontal ~30m	0.02μ	NA	See chart on Bathymetry.
		Bottom Characteristic	Global (coastal)	NA	NA	Charts, Maps	Not Specified	0-200m	Horizontal ~30m	0.02μ	NA	Information required includes consolidated or unconsolidated, type, plant growth, and topography.
MAPPING AND HYDROGRAPHY	• Location and position of shoal areas • Water depth in coastal and shoal areas	Water Depth (Ocean Bottom)	Regional (coastal)	As required	NA	Analog, Digital, Chart, CRT Display	NA	~0.200m	Horizontal ~30m (camera) Vertical ~2m near shore, ~5m away from shore	0.01μ	NA	Charts at scales of at least 1:50,000 are required. ESSA/ C&GS has the major responsibility for the coastal areas of the U.S. and its possessions. The Navy has the major responsibility for providing bathymetric maps of non U.S. areas.

Table 5-A-1 (Cont'd.)

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
(Cont'd)	(Cont'd)	(Cont'd)	Global (coastal)	As required	NA	Analog, Digital, Chart, CRT Display	NA	~0.208m	Horizontal ~30m (image) Vertical ~2m near shore, ~5m away from shore.	0.01μ	NA	The measurement of ocean color using cameras and scanners shows the highest feasibility for space deployment. Pulsed laser techniques possess very high resolution (0.2m) from aircraft altitudes. Other techniques include wave refraction analyses and thermal anomaly detection.
WEATHER FORECASTING AGENCIES	Accurate and synoptic information on these ocean features affecting: • Ocean circulation • Heat budget • Weather	Sea Surface Temperature	Global	4 per day*	Realtime*	Digital	1 per* 50,000km^3	-3° to +35°C	500km*	NA	1°C	A wide range of data input frequencies is called for depending on how the data is to be used. For developing global prediction models historical data is sufficient; realtime updating of models and forecasting – near realtime data is needed.
		Sea Ice • Thickness • Extent	Regional	Daily-Weekly	24 hours	Digital	• 1 per km^2 • NA	• 0-28m • NA	• 1m • 1km	NA	1°C	
		Sea State	Global	Daily	24 hours	Digital	Not Specified			NA	NA	Information on general sea state conditions is required, however, not in the detail that is required for the shipping industry.
		Currents • Extent • Velocity • Direction	Global	Daily-Weekly	24 hours	Digital	1 per 500km^2	• Up to 50km^2 • 0.5-10kt • 0°-360°	• 1000m • 2kt • 5°	0.01μ	1°C	
SCIENTIFIC AND CULTURAL STUDIES	Heat transfer Thermal pollution Thermal structure Forecasting currents	Sea Surface Temperature	Local	Daily or	NA	Digital, Computer Contoured Isotherm Charts	1-5 per km^2	-5°C to +35°C	25-500m	NA	0.1° to 1.0°C	Most requirements are for sporadic data over small areas. Data is used for a wide range of studies as is indicated in the spread of the requirements.
			Regional (coastal)	Daily or as required	NA	Chart, Digital	1 per 28km^2	-5°C to +35°C	<1km	NA	0.1° to 1.0°C	
			Regional	As required	NA	Chart, Digital	1-2 per 400km^2	-5°C to +35°C	1-10km	NA	0.3° to 1.0°C	Requirements are for tuna research in the Eastern Tropical Pacific fishing region.
	Chlorophyll	Ocean Color	Regional (coastal	Daily	NA	Maps, Analog, Digital	2-4 per km^2	0.1 to 1.0 mg/m^3	500m to 1000m	0.01μ to 0.0075μ	NA	
	Upwelling El Nino	Surface Salinity	Local	As required	NA	Analog, Digital	Not Specified	0.01-40 parts per thousand	Not Specified	NA	Not Specified	Basic research only – it appears micro-wave techniques operating at 1 GHz may be able to determine salinity in coastal areas.

*U.S. Weather Bureau requirement.

Table 5-A-1 (Cont'd.)

Use/ Application Area	Information Required by User	Ocean Features to be Observed	Geographic Coverage Required	Input Frequency	Input Timeliness	Data Format	Data Points Required	Parameter Range	Resolution			Comments
									Spatial	Spectral	Temp.	
(Cont'd)	Radar scattering cross sec.	Wind/Sea State	Local	As required	NA	Analog, Digital	Not Specified		Not Specified	NA	NA	
	Sea surface topography	• Currents • Tides • Eustatic changes in sea level	Regional	Daily	NA	Map	1 every 2-3 sec for narrow features 1 every 10-20 sec for wider features	10m	Vertical ±0.1 to 1.0m	NA	NA	Theoretical research into electromagnetic wave scattering from a non-linear sea is a necessary step towards 10-cm resolution of sea surface heights.
	Water depth	Ocean Color	Local	As required	NA	Photo	NA	Maxi. Water penetration	~30m	0.01μ	NA	Films, filters, spectrum and data processing techniques need to be determined to insure maximum water depth penetration.
	Fish schools/ species	Bioluminescence	Regional (coastal)	As required	NA		To be Determined	Not Specified	~15m	NA	NA	An image intensifier has been tested to determine its applicability for locating fish schools.
		Fish Oil Slicks	Regional (coastal)	As required	NA	Spectral Curves	To be Determined	To be Determined	Not Specified	Not Specified	NA	
		Pelagic Fish Species	Regional (coastal)	As required for test	NA	Spectral Reflectance	Not Specified	Visible Spectrum-0.4-0.7μ	~15m	200Å	NA	Laboratory tests have been successful, aircraft tests are now required to continue feasibility studies.

APPENDIX B

TYPICAL INSTRUMENT PAYLOADS

APPENDIX B

Components of typical payloads for Oceanography R&D sortie missions are described. This description is incomplete in that every instrument proposed is not detailed in every aspect. The sortie mode is suggested since it affords the intercomparison of instruments suggested earlier and allows the experimenters on board to be selective in choosing those regions of viewing for comparison purposes. The instrumentation under consideration is primarily that mentioned earlier. Table 5-B-1 summarizes more details of these devices. In general, the pointing of the instruments is required to 0.5°-1.0° with a stability of 0.1°-1.0°, depending on the experiment combination used. Cross-track rates should not exceed orbital rate. All optical devices will be concerned with the contamination problem, since pallet mounting (i.e., exterior to the sortie lab) is generally assumed.

The following are 3 examples of potential instrumentation complements for OR&D missions:

- Payload i — Ocean Surface Spectroradiometer (OSS), Sea Surface Temperature Infrared Radiometer (SSTIR), Advanced Instruments, (High Resolution Pointable Imager (HRPI).

- Payload j — Passive Microwave Radiometer, Sea Surface Temperature Infrared Radiometer (SSTIR), Advanced Instruments, Ocean Surface Spectroradiometer (OSS).

- Payload k — Radar (active microwave), High Resolution Pointable Imager (HRPI), Sea Surface Temperature Infrared Radiometer (SSTIR), Ocean Surface Spectroradiometer (OSS), Advanced Instruments.

In general, it is estimated that OR&D mission will require one or two persons in the experimenter (or Payload Specialist) role (i.e., exclusive of the two-man crew and the Mission Specialist). (NOTE: The term Experimenter is preferred to that of Payload Specialist since it more accurately describes the activity performed by this individual in the shuttle sortie mode.) On some missions three or four experimenters may be desired to assure optimum utilization of observation time.

SUPPORTING INSTRUMENTATION

For most sortie lab missions there are a number of pieces of equipment which are generally desired to support the experimenter. Those identified by the

Table 5-B-1

Typical OR&D Mission Payload Instrumentation

	Instrument					
	OSS	SSTIR	Adv. Instru.	HRPI	Passive MW Rad. OM.	Radar (Active MW)
Weight, lb (kg)	55 (25)	45 (20.5)	1200 (545)	165 (75)	80 (36) — Elect. 120(55) — Ant.	300(136) — Elect. 65(29.5) — Ant.
Volume, ft^3 (m^3)	2.37 (0.06)	2 (0.06)	40 (1.14)	5 (0.14)	12(0.34) — Elect. 300(8.5) — Ant.	12(0.34) — Elect. 176(5.0) — Ant.
Data: Acq. Rate Storage Dump Rate	565 kb/s	330 kb/s	10^9 bits	30 Mb/s 30 Mb/s	100 kb/s 0	30 Mb/s (max.) $3.6\ (10)^9$ bits 6 Mb/s
Power, watts and Thermal (BTu)	30	25	3000 110V, 60N 30 30 DC	75	200 (700)	300 (1000)

Oceanography Working Group are:

- Window — A nadir-looking view port for the use of the experimenter is almost mandatory. An alternative may be a TV monitor available on-call which will give that view with a field of view larger than that of the various sensors.

- Documentation Cameras — Wide and narrow-field cameras approximately boresighted to the experiment's instrument array is of great value for use by the experimenter as supplementary documentation if he so desires. Automatic sequencing should also be available (for $\approx$ 10 percent overlap). Hand-held cameras for use inside the sortie lab to document photographically such things as equipment modifications and set up changes are also suggested.

- Computer — A small, general-purpose computer is required for conversion of selected channel voltages to engineering units through either table lookup or simple arithmetic operations. (This unit may be used in conjunction with the Data Acquisition System.) Capability is required to display via TV or on-line printer key experimental results of real-time interest for the monitoring of operation of the instrumentation.

- Graphic Station — A general purpose, computer-coupled graphics station is required for looks at experiment outputs as a function of time, position, or other parameters. This is not a real-time display but would be used in evaluating experiment results prior to additional data gathering.

- TV Display — A two-channel display (similar to CV-990 equipment) is suggested. One channel displays output from avionics or inertial navigation system (latitude, longitude, time, altitude, and attitude, for example. The other channel displays earth view in sensor-pointing direction encompassing, at least, the field of view of the sensor. A capability to use this same display to view instrumentation on pallet and EVA activities is also desired.

- CRT Motion Picture Camera —The capability of a CRT equipped with a motion picture camera is considered worthwhile for the basic sortie lab instrumentation.

- Spectrum Analyzer — This instrument is required to support basic trouble-shooting of RFI, EMI problems.

- Communication Link to Ground — The experimenter should have a separate communication link to the ground for experiment related use only.

APPENDIX C

MISSION PARAMETERS

APPENDIX C

A few remaining characteristics of oceanography missions are described in the following:

Table 5-C-1

	Inclination	Altitude	Duration
OR&D 1	Sun Sych.	↑ Low (200 n.mi.) ↓	↑ Maximum Shuttle Capability ↓
OR&D 2	Near Polar		
OR&D 3	77°, 64° R (Typ.)		
OR&D 4	Low, 28° (Typ.)		
001	Near Polar Sun Synch. (Typ.)	400-600 n.mi.	Satellite, 1 year Shuttle, several days
002	77°, 64°R (Typ.)	Low	7-14 days

Several comments are required to add emphasis to this tabulation:

- The numerical listing above is not meant to be a specific sequence of flights or necessarily one of each per year. Experiment objectives and the individual payloads will lead to the orbital characteristics desired. It is anticipated, however, that solar angle constraints may be included in some of the operational requirements.

- In general, the desired inclinations are high (i.e. greater than the launch site latitudes.)

- Low altitudes are generally satisfactory for the R&D and operational 002 sortie modes. Other constraints will generally be more important. This is illustrated by the 77° and the 64° retrograde orbits noted where optimization of particular coastline geographic coverage is of prime importance.

- The seven-day capability initially planned for the sortie mode is considered minimal for the R&D testing. An increase in this duration to at least 30-day capability early in the program is encouraged.

- The operational 001 type mission considers the launch of an automated spacecraft which would have at least a one-year lifetime. It is anticipated that the shuttle be required for additional support for these launches, such as in the assembly and installation of a large microwave antenna with that spacecraft prior to its insertion into the high altitude orbit.

PRELIMINARY REPORT
OF THE
EARTH RESOURCES AND SURFACE ENVIRONMENTAL QUALITY
WORKING GROUP

CONTENTS

	Page
INTRODUCTION	6-1
GOALS AND OBJECTIVES	6-4
REALIZATION OF OBJECTIVES	6-8
APPENDIX A THE EARTH RESOURCES LABORATORY	6-A-1
APPENDIX B EARTH RESOURCES SURVEY (CONTINGENCY MISSION)	6-B-1

PRELIMINARY REPORT OF THE EARTH RESOURCES AND SURFACE ENVIRONMENTAL QUALITY WORKING GROUP

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INTRODUCTION

The task of the Earth Resources and Surface Environmental Quality Working Group was to outline the objectives for the discipline for the decade of the 1980's.

Identification of the potential contributions the sortie mode can make to specific discipline goals and objectives follow:

- Quantitative Relationships - Establishment of quantitative relationships between observable parameters and atmospheric or geophysical determinations (signature studies).

- Observation Concepts - Demonstration of the operational validity of specific observation concepts or techniques on a global scale, including the correlation of space observations with aircraft and surface-based measurements.

- Flight Instrumentation - Development, test, and calibration of eventual operational flight instruments in experimental space flight missions.

- Measurement Missions - Earth resource measurement missions that utilize unique shuttle capabilities (i.e., orbit, man, unlimited weight and volume, etc.).

Descriptive titles of sortie missions for which requirements and characteristics are outlined in attached appendices.

- Earth Resources Laboratory
- Contingency Mission

Outline of the proposed total flight schedule of sortie and non-sortie missions needed to meet the discipline goals and objectives.

1979 - 0 * This represents only those sortie missions considered desirable during this time span.
1980 - 1
1981 - 1
1982 - 1
1983 - 1
1984 - 1
1985 - 1
1986 - 1
1987 - 1
1988 - 1
1989 - 1
1990 - 1

Requirements this type mission places on the shuttle if the potential contributions are to be realized.

- Length of flights: 7 days, ecological missions - 30 days
- Orbit: 60° acceptable until 90° inclination available
- Data requirements: 50 to 100 mbs
- Role and number of personnel in orbit: 4 (2 on 2 off/12 hr. shifts)
- Stabilization and pointing: 0.5° pointing/0.05° sec rate
- Power and thermal: 400 Hz/28 volts/4kw-ave
- Weight and volume: N/A
- EVA requirements: probable if task cannot be accomplished with remote manipulators (erect and align large antenna arrays)

- Correlative measurements: as noted
- General support equipment: as noted in Appendix
- Documentation requirements: minimal
- Special operating constraints: all cameras located in pressurized environment; pallet must be in "Z" local vertical
- Contamination requirements: sensitive optical surfaces

Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space.

- Reduction of current Apollo-Skylab specifications
- Mainline sensor development will be an in-house NASA function

Brief description of estimated magnitude of sortie mission user community.

- Hundreds as indicated by ERTS and EREP proposals, followed by pre-operational and prototype operational requirements by user agencies.

Recommended approaches for interfacing with the user community.

- Inter-agency Coordinating Committee of Earth Resources Survey Program is the recommended approach.

Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

- Discipline crew training
- Flight of SR&T or AAFE breadboard experiments
- Continued evaluation of Role of Man in Earth Resources Surveys, such as aboard aircraft
- Annual operational cost in shuttle simulation aircraft should be underwritten and not charged to individual instrument developer.

GOALS AND OBJECTIVES

The goals and objectives of the Agency in Earth Resources are intimately related to a set of overall goals and objectives which describe the application of remote sensing of the earth's resources from space. Achievement of the overall goals and objectives must involve a combination of efforts by NASA, other government agencies (federal and state), industry, and the ultimate receiver of the benefits from space remote sensing, the individual citizen.

NASA's general roles and responsibilities are:

- Develop sensor systems necessary for the collection of remotely-sensed data.
- Test these sensor systems in the real environment, both in a research sense and in the development and pre-operational tests and simulations.
- Develop data processing methods necessary for handling the large quantities of data involved. Concepts for solution of the data processing problems will include in-flight as well as ground systems.
- Develop ecological models necessary for the understanding of remotely sensed resource information.
- Develop better understanding of the reflectance and radiation properties of biological and physical materials in the laboratory and in the field and identify means for discrimination from high altitudes and space. The following list of goals and objectives include the end objectives, requiring combined efforts of NASA and others for achievement.

AF AGRICULTURE/FORESTRY/RANGE RESOURCES

- AF-1 Identification, Measurement, and Monitoring — The classification and inventories of plant resources on a periodic and continuing basis by the remote sensing of agriculture, forests, and rangeland.
- AF-2 Plant Stress Detection, Assessment, and Loss Minimization — Assessments of plant stress on a periodic and continuing basis by the remote imagery and sensing of plant diseases and adverse plant climate.
- AF-3 Yield Prediction — Accurate and rapid inventories to determine optimum product mix and harvest time by the remote sensing of agricultural and livestock areas.

ML MINERAL AND LAND RESOURCES

- ML-1 Exploration — Mineral and land resource identification and location inventories in the form of geological maps by the remote sensing of minerals, fuels, and geothermal power sources.

- ML-2 Geological Hazards — Reliable predictions of hazards in areas susceptible to damage by volcanic eruptions, earthquakes, seismic sea waves, and landslides.

- ML-3 Landform Analysis — Terrain mapping to delineate continental structures by remote sensing of landforms.

LU LAND USE

- LU-1 Land Use Classification and Changes — Current and change use-classified maps and other information on a periodic and continuing basis by means of remote sensing of urban and rural areas.

- LU-2 Regional Planning -- Urban and rural land-use and economic activity data by means of remote sensing of regional areas on a periodic and continuing basis.

- LU-3 Archeology — Delineation of areas of interest and location of unknown sites by the remote sensing of archeological regions.

- LU-4 Disaster Assessments — Disaster assessments during or immediately following a natural or man-caused disaster and rapid data dissemination to the pertinent agencies.

- LU-5 Demography — Inventories of size, density, and distribution of population by the remote sensing of populated areas on a periodic and continuing basis.

WR WATER RESOURCES

- WR-1 Water Distribution and Changes — Inventories of drainage basins and river meander by the remote sensing of watershed areas and rivers.

- WR-2 Snow Surveys and Changes — The determination of water contents and rate of melt on a periodic and continuing basis by the remote sensing of snow and ice packs.

- WR-3 Water Quality Evaluation — Water quality measurements by the remote sensing of water bodies to determine the amount and types of parameters present affecting water quality.

- WR-4 Estuarine Dynamics — The determination of water mixing and composition by the remote sensing of estuaries.

- WR-5 Flood Prediction and Assessment — Reliable flood prediction and assessment by the remote sensing of snow melt and flood plains, seasonally on a periodic basis.

MR MARINE RESOURCES

- MR-1 Monitoring Pollution — The identification of oil slicks, effluents, sediment and their transport on a continuing basis by the remote sensing of the oceans, coastal zone, estuaries, lakes and rivers.

- MR-2 Measurement of Sea State — Measurement of sea state by the remote sensing of surface roughness (wind stress), wave heights, breakers and surf, daily on a continuing basis.

- MR-3 Identification, Measurement, and Monitoring of Marine Productivity The location, identification, measurement, and monitoring of phytoplankton, upwelling, and the biomass on a periodic and continuing basis by the remote sensing of the coastal zones and oceans.

- MR-4 Coastal Processes — Identification of channel and beach changes on a continuing basis by the remote sensing of shorelines and wetlands.

MC MAPPING AND CHARTING

- MC-1 Marine Bottom Topography Assessment and Changes, Bathymetry Definition of the marine environment and topography by the remote and in situ sensed marine subsurface properties.

- MC-2 Soil/Vegetation Relationships — The determination of soil types and associated vegetation classification on a continuing basis by the remote sensing of land areas.

- MC-3 Land Mapping — Precise geodetic control and the production of various maps and charts periodically on a continuing basis by the remote sensing of land areas.

- MC-4 Coastal Zone Mapping and Changes — The delineation of changes in the shoreline periodically on a continuing basis by the remote sensing of coastal areas.

- MC-5 Climatic Mapping — Maps of temperature, precipitation, and winds by the remote imagery and sensing in polar, desert, ocean and other remote areas periodically on a continuing basis.

- MC-6 Identification of Navigational Hazards — Identification and charting of hazards such as ice flows, channel sedimentation, and other natural or man-caused obstacles on a continuing basis by the remote sensing of navigable waters.

IR INTERDISCIPLINARY REGIONAL RESEARCH

A complete multidisciplinary classification and description of a region's balance, benefits, and management requirements, on a continuing basis by the remote sensing of ecological test sites and areas whose resources are managed by local or state regional agencies.

EN ENVIRONMENT

- EN-1 Environmental Quality and Models — The construction of an ecomodel encompassing the atmosphere, hydrosphere, and lithosphere by means of the remote sensing of air, water, and land for pollutants, their source modes of transport and ultimate disposition.

- EN-2 Ecological Assessments and Models — Models of ecological dynamics, constructed and validated, by means of remote sensing of the parameters of productivity pressures, ecological system interfaces, wildlife migration, and other factors.

- EN-3 Public Health - Epidemiology — Determination of the patterns, interrelationships and transmission modes of epidemics by means of remote sensing of the effects of disease vectors of plant, animal, and human epidemics.

DI DATA INTERPRETATION RESEARCH

- DI-1 Information Extraction Techniques — Powerful new software to handle the multivariate environmental data in digital and analog form by

means of advanced computation techniques involving mathematics, statistics, and probability.

- DI-2 Models — Models enabling rapid and efficient data interpretation and classification of each type of information required for resource management.

- DI-3 Pattern Recognition — Accurate and reliable inventories compiled by means of image enhancement techniques and selection of optimum sensor parameters.

- DI-4 Multispectral Signatures — Classification of optimum discrimination parameters of multispectral signatures for seasonal changes.

REALIZATION OF OBJECTIVES

The potential contributions of the sortie mission to the Earth Resources disciplines can best be realized by establishing a flexible laboratory/facility in space to address the requirements noted above. The principal thrust of this type approach is to allow for flexibility in mission objectives. The Earth Resources Laboratory as described in Appendix A offers this capability in that it will utilize man's capabilities to augment the development and test of sensors plus limited operational measurements while taking full advantage of the capabilities of the shuttle (i.e., weight to orbit, volume, altitude, and inclination variations).

In analyzing the typical advanced developments and associated applications of future earth resources survey systems, the following discussion is provided. Advanced developments and associated applications anticipated in future earth resources survey systems are given below. The developments are grouped and keyed to the potential contributions listed in the Introduction.

- Cataloging of earth albedo characteristics with location, direct measurements of aerosols, and other atmospheric effects for a near-real-time connection of earth resources observations at optical frequencies (also a needed goal of the meteorological discipline.) (Quantitative Relationships)

- Improved multispectral scanners with respect to ground resolution (40 meters and less), scan efficiency, higher s/n for detecting low contrast targets (a moderate FOV of 100 nautical miles). The application of this scanner would be in global mapping of vegetation, soil type, tectonic features, hydrological features including flood areas, extent of sea ice, land use, and other important features. (Quantitative Relationships, Observation Concepts)

- High-resolution, pointable imagers, using solid-state linear array with ground resolution approaching 10 meters and a FOV of 20 nautical miles. Application would be for selective targets involving oil spills in coastal zones, shore-line changes following severe storms, wind damage survey, special land-use survey, and other uses. (Observation Concepts)

- Application of low frequency microwave radiometers (S-band) to low resolution, soil moisture mapping. Development of large deployable, bellows-type antenna. (Observation Concepts)

- Application of synthetic aperture, side-looking radar (polypanchromatic) for geological and geomorphic surveys independent of cloud cover. Also, to supplement passive microwave measurements of ice cover and soil moisture by removing ambiguities in information extraction. Progression in both the microwave and active radar measurements would be towards multifrequency capability. (Quantitative Relationships, Observation Concepts)

- Demonstration of feasibility of a large aperture telescope (3 meters) applied to a geosynchronous earth resource satellite. Application would be in continuous monitoring of fixed geographic areas. (Observation Concepts, Flight Instrumentation)

- Framing camera, such as a (4" 10,000 line RBV) camera for achieving greater accuracy in position location of terrestrial phenomena. Application would be in directing ground survey teams to areas of interest with respect to land marks or map coordinates. (Flight Instrumentation)

- Dual mode instruments, such as an electrically scanner-imaging spectrophotometer which can trade spatial for spectral resolution. Application would be in both coastal and open ocean application such as a survey of surface contaminants, possible mapping of chlorophyl contents, sedimentation surface distribution patterns in estuaries, and other uses. (Flight Instrumentation)

- Development of advanced spectrometer concepts such as Hadamard spectrometers, derivative spectrometers, correlation spectrometers, and other techniques compatible with bit-rate reduction for transmitted data. Application would be in man-imaging, spectroradiometeric data for soil, vegetation, hydrology, atmospheric, and other signature analysis. (Flight Instrumentation)

C3

- Development of large aperture (possibly to 10 meters x 10 meters), electronically scanned, slotted-waveguide array, microwave radiometer operating near 37 GHz for mapping ice fields and detecting open leads approaching 1 km in width. (Flight Instrumentation)

- Application of advanced camera/film systems for high resolution, metric quality mapping for cartographic and land use applications. (Flight Instrumentation)

- Development of on-board data processing, such as hybrid processors, spatial filtering, and other techniques for signature and pattern recognition of earth resource targets. (Flight Instrumentation, Measurement Missions)

- Commensurate development and application of precision altitude reference system (approaching 0.001°) for use with high resolution optical scanners. (Flight Instrumentation, Measurement Missions)

- Development of precision pointing platform for wide-band communications with TDRS. (Flight Instrumentation, Measurement Missions)

A separate and equally-important function of the Earth Resources Laboratory in a sortie mission will be the performing of operational measurements utilizing the unique shuttle capabilities. Taking full advantage of shuttle orbital characteristics one can anticipate the requirement and need for orbital parameter flexibility between flights (global targets), opportunity for timely high intensity regional coverage (disaster assessment), and the highly desirable requirement for an orbit experiment modification (unanticipated targets of opportunity). These type shuttle capabilities coupled with the availability of a discipline-trained crew provide a new dimension to certain operational measurements. The crew provides for on-line experiment participation in pattern recognition, real or near-real time interpretation, experiment modification, sensor selections, and the possibility of data screening and compaction. This type of an operational mission will also be used when it augments or fills a gap in the capabilities of the automated satellite program. This refers to the ability to accommodate large sensors, high power sensors, and those sensors generating high data rates. With these capabilities the shuttle sortie affords the earth resources disciplines the opportunity to clearly enhance their ability to attain the goals and objectives noted earlier.

APPENDIX A

THE EARTH RESOURCES LABORATORY

APPENDIX A

THE EARTH RESOURCES LABORATORY

The Lab will provide the following data systems:

- Instrument control panel and power supply
- Analog and digital signal display
- A to D and D to A conversion
- Single channel image display
- Additive color image display
- Computer processing capacity for pattern recognition algorithms
- Color coded pattern recognition display with capability for analog or digital input
- A control and cueing console for the Manned Earth Viewing System

The Lab will provide the following sensor systems:

- A Manned Earth Viewing System which will have a ground resolution of 2 meters at the eye piece from an altitude of 275 km with a bandwidth of 0.5 to 2.0 micrometers
- A MEVS target acquisition and control computer
- The computer will also provide for the slaved control of a gimballed instrument platform
- The gimballed platform will be in the external vacuum with cable link to the Lab
- A 50 megahertz precision pointing RF antenna to geosynchronous repeaters

RATIONALE FOR IN-FLIGHT IMAGE PROCESSING COMPUTER

There are three major uses of a computer of sufficient size, e.g., 360/44, to do on-board image processing for Earth Resources Sortie missions.

- Processing for decision making
- Analysis as a form of data compression and editing
- Information storage, retrieval, and cataloging

Decision making implies near-real time analysis aboard the spacecraft. For instance, if the position of fish schools is desired and the detection of the schools requires manipulation of the imagery, the usefulness of the information is lost if no computer is available to make an on-the-spot analysis.

Detecting forest fires from orbit will probably require some type of enhancement of the thermal imagery for proper detection. In addition the coordinates of the fire must be known accurately. A computer is, therefore, essential to make proper and timely use of the information. Change detection will play a role in any type of analysis of transient phenomena. Since transient phenomena by their nature require a quick response, the capability for that type of analysis must be available. Simple photographic overlays are not feasible because of the variations in viewing geometry between different orbits or times in one orbit. Cross-correlation and rubber sheet stretching techniques can only be done with a digital computer.

In line with cost reduction attempts, some form of massive data compression and editing is required. It is expected that man assisted by a computer will make an efficient data editor. Editing will take place in the process of target selection as well as in the on-board analysis and rejection of sub-standard data.

An additional form of data compression will consist of combining data before return to earth for further analysis. For instance, a particular Karhuenan-Loeve transformation could be carried out to reduce the 12-band scanner data to 4-band, according to the target objectives, for later analysis. On-board, real time analysis could also assure that the proper mix of bands was being made.

Information storage and retrieval requires a computer and, while it might not be justified on its own, it is a valuable adjunct to the decision making and analysis functions. For instance, for change detection it will be necessary to retrieve images taken at an earlier date. For analysis, stored ground truth information will be necessary. In addition the computer will provide a valuable bookkeeping

service to apply such aids as picture coordinates sun altitude to the images, thus saving appreciable time and confusion in the returned data.

The computer is, therefore, a necessary adjunct to man for decision making, data compression, and storage and retrieval using data obtained on an Earth Resources Shuttle Sortie mission.

APPENDIX B

EARTH RESOURCES SURVEY (CONTINGENCY MISSION)

APPENDIX B

EARTH RESOURCES SURVEY (CONTINGENCY MISSION)

DISCIPLINE AREAS

GOALS AND OBJECTIVES FOR THE DECADE OF THE 1980'S

One of the very highest priority objectives in terms of national and international significance is to achieve the capability of monitoring in real time or near-real time a whole family of transient or unscheduled events. These include catastrophic situations such as damage from hurricanes, tornadoes, flooding, earthquakes, volcanoes or tidal waves. They may include the sudden onset of widespread crop disease or damage, or of forest fires. Another category in this family is search and rescue missions.

CONTRIBUTIONS OF THE SORTIE MODE

The sortie mode is unique in that a specific sortie module could be designed to gather a variety of remotely-sensed data, and it could be dispatched to view any part of the world. Unfortunately a significant number of events require a quick reaction time which cannot usually be accommodated by launching a separate shuttle for that purpose, even if a shuttle were maintained in launch-ready condition dedicated to quick reaction requirements.

An alternate approach recognizes the probability that in the 1980's there would eventually be a situation where one or more shuttles would be in orbit at nearly all times. By equipping all shuttles with a basic capability for earth observations, initial coverage of unscheduled events could be provided with minimum delay. The use of a telescope and an x-band imaging radar with the human operator together with pointing capability, should provide a capability of viewing any place within the latitude limits of the orbit and with a reaction time within a few orbits.

MISSIONS REQUIRED FOR POTENTIAL CONTRIBUTION

It is proposed that a sortie mode capability be provided for all shuttles to be called up on a contingency basis when priority of monitoring the unexpected

event justifies a mission change. The following list indicates a preliminary evaluation of those missions which could accommodate the telescope and radar.

- Astronomy — No
- Physics — No
- Planetary — No
- Earth and Ocean Physics — Yes
- SATS Polar — Yes
- Communication/Navigation — Yes
- Life Sciences — Yes
- Material Sciences — Yes
- Space Station — No

INITIAL REPORT OF THE METEOROLOGY AND ATMOSPHERIC ENVIRONMENTAL QUALITY WORKING GROUP

CONTENTS

	Page
1980 DECADE – GOALS AND OBJECTIVES	7-1
SPACE SHUTTLE CONTRIBUTIONS	7-3
FLIGHT SCHEDULES	7-8

APPENDICES A THROUGH G

SORTIE MISSION CHARACTERISTICS AND REQUIREMENTS

APPENDIX A	7-A-1
APPENDIX B	7-B-1
APPENDIX C	7-C-1
APPENDIX D	7-D-1
APPENDIX E	7-E-1
APPENDIX F	7-F-1
APPENDIX G	7-G-1

INITIAL REPORT OF THE METEOROLOGY AND ATMOSPHERIC ENVIRONMENTAL QUALITY WORKING GROUP

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1980 DECADE - GOALS AND OBJECTIVES

Scientists in the discipline area of meteorology and atmospheric environmental quality are concerned with how the atmosphere works as a complex fluid-dynamical system. The study of how storms are produced, how pollution accumulates and is removed from the atmosphere, and how the ocean and atmosphere interact are but a few of the basic scientific problems that occupy many of the theoreticians. Although the research is primarily basic, the solution of each of these problems can be applied to immediate practical problems. In this decade, and the succeeding decade, the scientists must continue to attack fundamental scientific problems and at the same time direct more attention toward human needs; such as the intelligent control of air pollution, timely warnings or modification of dangerous weather events, and the growing economic and social importance of accurate weather forecasts.

The solution of the problems are feasible through the application of scientific and technological advancements. The application of science and technology in this and the next decade should be focused on the following national discipline objectives:

- Weather Prediction — Extend the capability for useful prediction of the weather and atmospheric processes
- Air Quality — Contribute to the development of the capability to manage and control the concentrations of air pollutants
- Weather and Climate Modification — Establish mechanisms for the rational examination of deliberate and inadvertent modification of weather and climate

- Weather Dangers and Disasters — Reduce substantially human casualties, economic losses, and social dislocations caused by weather

The NASA Meteorology Program has made significant contributions to the areas of Meteorology and Atmospheric Quality and will continue to do so. The Program's Objectives to support national progress during the next decade may be expressed as follows:

- M-1 Operational Support — Support the development of the operational meteorological and atmospheric quality satellite systems

- M-2 Weather Prediction — Develop space technology for determining the vertical structure of the atmosphere globally which, when supplemented by simulation techniques, models, and conventional observations, will provide required data with emphasis on large scale long-term weather forecasts

- M-3 Atmospheric Quality — Develop a space sensing capability to identify and quantitatively monitor the distribution of natural and man-made pollution in the lower and upper atmosphere on global and regional scales

- M-4 Weather and Climate Modification — Develop space observational and in-flight orbital experiments of cloud microphysical processes, gases and particulates, cloud dynamics, and radiation necessary for the rational examination, understanding, and modeling of deliberate and inadvertent weather and climate modification

- M-5 Weather Disaster Assessment and Warning — Develop and establish a system for continuous observation of atmospheric features to permit early identification and quantitative measurement of atmospheric conditions conducive to the formation of severe atmospheric phenomena (e.g., thunderstorms, tornadoes, hurricanes, air pollution episodes, etc.) to serve as a basis for timely warnings to the public

- M-6 Processes and Interactions — Investigate fundamental atmospheric processes and interactions on various temporal and spatial scales within the atmosphere; in response to solar imputs; and at the air-surface interface through the observation of the structure, composition, and energetics of the atmosphere by utilizing and developing space technology

The fulfillment of these objectives requires fundamental and applied scientific and technological research and development. The space shuttle can play a significant contributory role in the application of science and technology to the alleviation of national and international environmental problems.

SPACE SHUTTLE CONTRIBUTIONS

Three operational modes of the space shuttle will contribute to research and application in meteorology and atmospheric quality. They are:

- Sortie — Short duration missions of up to 30 days which will have the flexibility, versatility, and response time to act as a test, demonstration, and observing platform and space laboratory

- Staging — Orbital deployment of operational or R & D automated spacecraft with one or more propulsion stages

- Delivery, Servicing and Retrieval — Delivery of test or operational spacecraft into orbit with the capability of subsequent visiting for service, repair, or retrieval

The efforts in meteorology and atmospheric environmental quality are directed toward long term observation of the Earth environment and the operational applications of the observations. To achieve the effective operation of long-lived, automatic Earth observations platforms, there must be a phased development process. This process requires (a) the establishment of quantitative relationships between observable parameters and atmospheric observations; (b) the demonstration of the operational validity of specific observation concepts or techniques including the correlation of space observations with aircraft and/or surface based measurements; (c) the development, test and calibration of eventual flight and in-flight experimental and operational instrumentation; and (d) the deployment of orbiting satellite systems. The sortie mode is applicable to the first three phases while all three modes possess the means of contributing to the last phase. The areas of contribution are summarized in Table 7-1.

- Test and Demonstration — The meteorology and atmospheric quality programs can use a considerable number of sorties to conduct scientific and technological tests of measurement concepts and instruments, and the demonstration of the operational validity of concepts and techniques selected after a number of tests and analyses of the data. Appendices A and B give the characteristics and requirements for two possible types of missions.

  The types of instrumentation and concepts to be tested will vary widely. Generally, the shuttle will carry common facility instruments which will provide correlative and supporting data for the meteorological instruments and atmospheric quality instruments being tested. The last two types can at times overlap and be applicable to both meteorology and atmospheric quality.

Table 7-1

Space Shuttle Contributions to Meteorology
and Atmospheric Environmental Quality

Contribution	Mission Type	Shuttle Mode
Test and Demonstration	-Scientific test of measurement concept -Technological test of new instruments -Demonstrate operational validity	• Sortie
Support	-Calibration of sensors on s/c in flight -Participation in field programs -Weather danger and disaster assessment	• Sortie
Space Laboratory	-Zero-G cloud physics experiments -Test materials and components	• Sortie
Automated Satellite Deployment	-Orbiting of operational and R&D satellites	• Staging • Delivery, S and R

The following table gives examples of types of instruments that might be flown on the space shuttle:

Table 7-2

Examples of Types of Instruments

Type of Instrument/Measurement	Purpose
Common Facility	
Atmospheric Sounder	Vertical profiles of structure and composition
Multi-spectral imagers	Cloud cover, surface temperature, terrain cover, etc.
Mass Spectrometer	Environment outside spacecraft
Meteorology	
Advanced High Resolution Sounders	High spectral and spatial resolution for structure and composition
Passive Multi-Frequency Mircowave Radiometers with Large Deployable Antennas	Sea surface temperature, sea state, ice cover, water content (vapor & liquid), soil moisture, precipitation, etc.
Multi-Frequency Radars	Same as for passive microwave
Tunable Laser Radar	Cloud height, thickness, phase, and optical properties
Multi-Channel Cloud Physics Radiometer	Cloud phase and optical properties, aerosols
Sun Glint Scanner	Sea surface wind velocity
Hydrogen Alpha Emission of Sferics Sensor	Lightning observations, mapping of distribution and intensity of thunderstorms

Table 7-2 (Continued)

Type of Instrument/Measurement	Purpose
Microwave-occultation	Use of two spacecraft for atmospheric reference level
Stellar or Solar Occultation	Structure and composition
High Resolution Spectrometer	Emission over IR spectrum at high spectral resolution, e.g. $\sim 0.1\,cm^{-1}$
Highly Accurate Solar Constant Measurement	Measurement of less than 0.5%
Advanced Radiation Budget Radiometer	Heat budget and circulation
Atmospheric Quality	
Tunable Laser	Vertical profiles of trace gases, gaseous pollutants and particulates
Laser Raman Forward Scatter	Ground-spacecraft system for gaseous pollutants
Advanced Passive Sensors Laser Heterodyne Radiometer Gas Filter Correlation Analyzer High Speed Interferometer Correlation Spectrometer Polarimeter	These various methods may measure particulate and gaseous pollutants (CO_2, CO, SO_2, O_2, N_2, etc.)

Correlative airborne and ground based measurements are needed over test sites for many of the above types of experiments.

- Support — The flexibility, versatility and quick response time of the space shuttle to a wide variety of situations and requirements, together with its maneuverability and mission repeatibility provide opportunities for a number of support activities.

  It can provide a means of calibrating instruments in-flight aboard long-lived operational and R & D spacecraft. The performance of various kinds

of sensory subsystems can undergo change and degradation in flight which is difficult to detect or evaluate, but which may have considerable impact on the application and interpretation of the data. With duplicate sensor systems and/or correlative systems, the shuttle can fly over the same area and at the same time as the automated spacecraft, making measurements with systems which can be recalibrated after the return of the shuttle, thus affording a check on sensor performance and quality of observation.

In meteorology there are many field programs which could benefit from the support of a specially dedicated spacecraft such as the space shuttle. Examples of such programs are the Barbados Oceanographic and Meteorological Experiment (BOMEX) and the planned GARP Atlantic Tropical Experiment. While automated satellites in geostationary or polar orbit would also give support, the space shuttle with the interchangeable payloads and crew could provide special observations. For such support, a disciplined trained observer would be required as well as instruments such as cameras, imagers, sounders, lasers, spectrometers, etc. Similar types of field programs could be established for Atmospheric Environmental Quality supported by a trained observer in a space shuttle with instruments which are applicable to atmospheric quality. Support might also include the deployment and recovery of one or more automated satellites which will perform for a period of time such as a month or season.

In weather danger and disaster assessment the space shuttle would have an opportunity to provide basic information for the exploration and understanding of the development and behavior of the atmosphere in perilous situations. Danger and disaster assessment includes the behavior and characteristics of the atmosphere before, during, and after the occurrence of a disasterous atmospheric event; as well as the physical terrestrial damage. The quick response and versatility of the space shuttle will provide a means of obtaining the observations needed to understand and predict the occurrence, growth, and dissipation of dangerous atmospheric episodes.

Appendices C and D give the characteristics and requirements of two possible space shuttle support missions.

- Space Laboratory — The shuttle sortie mode is ideally suited for a space laboratory mission under zero-G and space environment conditions. An example of this is the Zero-G Atmospheric Cloud Physics Facility which is designed to conduct experiments to provide data needed for cloud physics and weather modification studies. The experiments will vary from simple observation of cloud chamber actions to compiex measurements of physical processes. They include processes such as nucleation, droplet growth,

scavenging, charge separation, and optical properties. While this type of experimentation places very little constraint on the orbit, it does require the manned attendance and conduct of the experiment. Appendix E gives the characteristics and requirements for such a mission.

The test of materials and components performance is another space laboratory activity which would provide valuable information for the improvement and advancement of meteorology and atmospheric quality satellites. While the conduct of this type of experimentation may properly belong and be conducted under the aegis of Space Technology, it is felt that the subject should be emphasized here because of its importance to meteorology and atmospheric quality. Appendix F gives the characteristics and requirements of a representative mission

- Automated Satellite Deployment — The delivery of operational and R&D satellites for meteorology and atmospheric quality will probably require the deployment of the spacecraft with one or more propulsion stages depending upon the desired orbit. The weights of the spacecraft are of the order of 500 to 2500 kg. The types of orbits required are circular sun-synchronous at 1000 km or higher and circular geostationary at 36,000 km. These are long-lived satellites which could benefit substantially from any servicing or retrieval-in-orbit capability that the space shuttle might provide. Appendix G gives the characteristics and requirements of such missions.

FLIGHT SCHEDULES

The number of flights during the decade of the 1980's will undoubtedly vary with the type of contribution. For Test and Demonstration it is estimated that there will be from one to four missions per year. This may include the re-flight of an identical payload, improved instruments based on the results of earlier flights, or an entirely different payload.

Support missions can be highly variable from one year to another depending upon the types of programs that are implemented or the spacecraft flown. Requirements are estimated to be one to four flights per year.

In the Space Laboratory, since the constraints are less restrictive than in the other cases and there is a wide variety of experiments which can be conducted with the same equipment, it is estimated that there will be one to six flights per year.

It should be noted that the three sortie type missions are not mutually exclusive. In many instances two or three different activities might be conducted on the same mission.

For Automated Satellite Deployment the schedule will vary with the missions of the satellites. For the period 1979 - 1990 the operational satellite schedule is estimated to be

Period	Description	Schedule
1979-1986	Meteorology, circular polar orbit	2 per 3 years
	Atmospheric quality, circular polar orbit	2 per 3 years
	Meteorology, geostationary orbit	1 per 2 years
1986-1990	Combined meteorology and atmospheric quality, circular polar orbit	1 per 2 years
	Meteorology, geostationary orbit	1 per 2 years

For the R & D satellites, the mission may be either meteorology, atmospheric quality, or a combination of both. For the period 1979-1990, the schedule is estimated to be:

Period	Description	Schedule
1979-1990	Near Earth orbit	1 per 2 years
	Geostationary orbit	1 per 2 years
	Low Earth orbit	as required

APPENDICES A THROUGH G

SORTIE MISSION CHARACTERISTICS AND REQUIREMENTS

APPENDIX A

A. Discipline Area: Meteorology and Atmospheric Environmental Quality.

B. Sortie Payload Title: Test and Demonstration of Visible and Infrared Meteorological and Air Quality Sensors and Flight Equipment.

C. Sortie Utility: The sortie mode is ideally suited for the conduct of this mission since it provides the necessary combination of relatively short-term turnaround for conduct of the experiment and receipt of results, accomodations for required volume and weight needed for the multi-sensor experiments, availability of man to conduct experiments, and required near Earth orbital capability coupled with the ability to easily change orbit.

D. Requirements:

- Length of Flights — 7-30 days.
- Orbit — 0° - 110° inclination and 350 - 900 km altitude.
- Data Requirements — Near real time "quick look" data transmission capability required for 30 day missions, digital and analog tape records, and performance log.
- Role and Number of Personnel — Payload specialist knowledgable in instrumentation with some background in the meteorological and environmental sciences would be required.
- Stabilization and Pointing — Earth viewing with absolute pointing of 0.25° and relative pointing accuracy of 10 arc-seconds. Image motion compensation and scanning platforms would be required for several experiments.
- Power and Thermal Requirements — Typical instrument: 100w/Multiple Sensor mission: 2 kw. Thermal environment for sensor package: range, 5-25°C/stability, 1-2°C.
- Weight and Volume — Typical package: 45 kg and 0.3 m^3/ Multiple Sensor mission: 900 kg and 3.5 m^3.
- EVA Requirements — Access of payload specialist to instrument bay.
- Correlative Measurements — Photographic imagery of area viewed by sensor. Excellent ephemeris will be required for several experiments.

It would be highly desirable to have a sampling system, such as mass spectrometer, to define the exterior spacecraft environment.

- General Support Equipment — The following is a list of general support equipment required; tape recorders, oscilloscopes (nanosecond response) and digital counters.

  Additionally, limited onboard computing capability would be useful. Consideration should be given to the supply of fairly large quantities of liquid nitrogen and helium for sensor and instrument cooling and other uses.

- Documentation Requirements — Minimum documentation consistent with assurance of experiment accomplishment. Exact needs to be determined.

- Special Operating Constraints — Ability to scan limb of Earth will be required.

- Contamination Requirements — CO_2 & H_2O vapor must be excluded from most sensor packages to the maximum extent possible. Contamination of optical surfaces by spacecraft effluents cannot be tolerated. Dry N_2 purging between the instrument package and the viewing window appears to be the most desirable means.

E. Policies and Procedures: Establishment of a procedure is necessary for flexible and short-time turnaround approvals for repeated flights of the laboratory based on experimenter needs. The current Apollo type "man-rating" of laboratory and associated equipment is a maximum requirement. Additionally, it is believed that the pre-flight training of the payload specialist should be held to a minimum consistent with safety and successful completion of the experiment. A considerable cost-saving could be achieved if the reliability of the flight hardware were left primarily to the experimenter to the maximum extent possible consistent with safety.

F. User Community: The user community would encompass the international community of meteorological and environmental scientists. It would also include those agencies of the Federal and State governments with a responsibility for monitoring the environment.

G. Community Interface: User community interface should be through direct involvement of users in the definition, design, construction and flight of the multi-experiment laboratory. Professional society presentations and publication of papers should be prepared and symposium/workshops should be conducted. Emphasis should be on the meteorological and atmospheric environmental quality user applications of experiments.

H. Future Actions: Future actions necessary to implement the experiments on sortie missions include a strong and viable Supporting Research and Technology (SRT). The areas encompassed are sensor concepts, detectors, optics, cryogenic devices, and laser systems. The SRT programs should include basic spectroscopy of polluted atmospheres obtained in the laboratory as well as the field. Another SRT area is the development of algorithms for conversion of raw data that will be obtained from such sortie operations. The present Advanced Applications Flight Experiment (AAFE) type programs must be continued. The specific development of shuttle payloads such as the laser radar systems and the high speed, high resolution interferometer must not only be placed in a continuing status, but must be strengthened.

APPENDIX B

A. Discipline Area: Meteorology & Atmospheric Environmental Quality.

B. Sortie Payload Title: Test and Demonstration of Microwave Meteorological and Air Quality Sensors and Flight Equipment.

C. Sortie Utility: The sortie mode is ideally suited for the conduct of this mission since it provides the necessary combination of relatively short-term turnaround for the conduct of the experiment and receipt of results, accommodations for required volume and weight needed for the mulu-sensor experiments, availability of man to conduct experiments and required near earth orbital capability coupled with ability to easily change orbit.

D. Requirements:

- Length of Flights — 7-30 days.
- Orbit — 0° - 110° inclination.
- Data Requirements — Near real time "quick look" data transmission capability required for 30 day missions. Telemetry of source real time data will require approximately 30-35 MHz bandwidth.
- Role and Number of Personnel — Payload specialist knowledgable in instrumentation with some background in the meteorological and environmental sciences.
- Stabilization and Pointing — Earth viewing with absolute pointing 0.25°.
- Power and Thermal Requirements — Power will range from approximately 600 watts to 1 kilowatt depending on spatial resolution finally determined as optimum for use. Temperature will range from internal spacecraft (22° C) for the equipment to outside ambient for the antenna.
- Weight and Volume — Estimated weight of 135 kg with volume of 0.06 m^3 for internal spacecraft electronics. Antennas for the radar are approximately 9.0 m x 0.6 m x 0.3 m, and for the passive radiometers from 9.0 m to 30.0 m in diameter.
- EVA Requirements — Require EVA possibly to deploy and erect passive microwave antennas (9 - 30 m) and to fold up and stow antennas before reentry of shuttle.

- Correlative Measurements — Photographic imagery of area viewed by sensor; excellent ephemeris will be required for several experiments. It would be highly desirable to have a sampling system, such as mass spectrometer, to define the exterior spacecraft environment.

- General Support Equipment — The following is a list of general support equipment required: tape recorders, oscilloscopes (nanosecond response), and digital counters.

  Additionally, limited on board computing capability would be useful. Consideration should be given to the supply of fairly large quantities of liquid nitrogen and helium for sensor and instrument cooling and other uses.

- Documentation Requirements — Minimum documentation consistent with assurance of experiment accomplishment. Exact needs to be determined.

- Special Operating Constraints — Ability to scan limb of Earth will be required.

- Contamination Requirements — None.

- Other — Dry N_2 purging from instrument package to viewing window appears to be the most desirable means to exclude contaminants from the fields of view of the common facility instruments operating in the infrared and possibly other affected parts of the spectrum.

E. Policies and Procedures: Establishment of a procedure is necessary for flexible and short-time turnaround approvals for repeated flights of the laboratory based on experimenter needs. The current Apollo type "man-rating" of the laboratory and associated equipment is a maximum requirement. Additionally, it is believed that the pre-flight training of the payload specialist should be held to a minimum consistent with safety and the successful completion of the experiment. A considerable cost saving could be achieved if the reliability of the flight hardware were left primarily to the experimenter to the maximum extent possible consistent with safety.

F. User Community: The user community would encompass the international community of meteorological and environmental scientists. It would also include those agencies of the Federal and State Governments with a responsibility for monitoring the environment.

G. Community Interface: User community interface should be through direct involvement of users in the definition, design, construction and flight of the multi-experiment laboratory. Professional society presentations and publication

of papers should be prepared and symposium/workshops should be conducted. Emphasis should be on the meteorological and atmospheric environmental quality user applications of experiments.

H. Future Actions: Funding for SRT needs to be presently increased to provide for development of multifrequency radar and smaller lightweight, lower power-consuming and longer life transmitters and receivers for multifrequency radar systems. Efficient antennas for multifrequency radars need to be investigated. Large unfoldable and geometrically accurate passive microwave antennas (scanning and non-scanning) need to be developed to eliminate the effects of distortion due to thermal gradients. Digital on-board recorders and wideband telemetry systems for imaging radars will be required. Low noise, low loss, and stable radiometer systems are needed for higher sensitivity. The pr Advanced Applications Flight Experiments (AAFE) Program should be c d.

APPENDIX C

A. Discipline Area: Meteorology & Atmospheric Environmental Quality.

B. Sortie Payload Title: Support of Operational Spacecraft Sensor Calibration.

C. Sortie Utility:

- Need for return of instruments.
- Mission flexibility allowing checking of several spacecraft.
- Short duration and repeatable mission desirability.

D. Requirements:

- Length of Flights — One day to one week.
- Orbit — High inclination with other parameters adjusted to permit under flight of high orbiting spacecraft for a period of time.
- Data Requirements — 1000 bits/sec for 1 hr/day.
- One man to operate equipment including aiming, calibration and checking results.
- Stabilization and Pointing — Earth viewing, stabilization and pointing should be adequate for man to keep a known target on the ground (of desert size) in view of instrument. Limb of the Earth scanning may also be required.
- Power and Thermal Requirements — Peak power, 500 w; average power, 200 w: current 28 VDC and 110 VAC, 60 Hz: cooler may be required to cool parts of apparatus to 170°K.
- Weight and Volume — 90 kg, 0.35 m^3.
- EVA Requirements — Not required.
- Correlative Measurements — Navigational data.
- General Support Equipment — Data tape recorders, amplifiers.

- Documentation Requirements -- Operator's notes.

- Special Operating Constraints — Must intersect orbit of preselected satellites over specified areas and be concurrently pointing toward Earth.

- Contamination Requirements — Clean radiometer apertures required, i.e., no films or deposits on windows.

- Other — Instrument to be exposed through an airlock.

E. Policies and Procedures: Relaxation of weight, power, volume, and particularly reliability and quality assurance requirements to achieve cost reductions.

F. User Community: The user community primarily consists of NOAA, but also includes DOD, other government agencies, universities, foreign weather services, and other agencies in many countries.

G. Community Interface: Monthly notices concerning planned calibrations.

H. Future Actions: SRT required to develop primary calibration standard in ultraviolet and more rapid-response sensor instrumentation.

C

APPENDIX D

A. Discipline Area: Meteorology and Atmospheric Environmental Quality.

B. Sortie Payload Title: Participation in Field Programs and Weather Danger and Disaster Assessment.

C. Sortie Utility:

- Ability to choose orbit and time.
- Necessity of having a discipline trained observer to assess conditions and modify the experimental program accordingly.

D. Requirements:

a. Length of Flights — 2-30 days.

b. Orbit — According to purpose, inclination and height will vary. Spacecraft is to cover area of interest which may range from a single large region (e.g., Eastern half of U.S. or Tropical Atlantic) to the entire globe.

c. Data Requirements — One megabit per sec. for s lected disaster areas of about 1 minute duration; about 10^5 bits/sec for longer periods.

d. Role and Number of Personnel — 1 trained meteorologist, 1 technician to operate equipment and assess potential target areas and instruments to be used.

e. Stabilization and Pointing — Compatible with requirements for Earth viewing imagers; sounders, etc., over the target area. However, there may also be a requirement to scan the limb of the Earth at the same time.

f. Power and Thermal — Average power, 200 watts; peak power, 500 watts; coolers may be required to cool some parts of apparatus to 170°K.

g. Weight and Volume — 225 kg, 0.9 m^3.

h. EVA Requirements — None.

i. Correlative Measurements — Navigation (time, position, attitude).

j. General Support Equipment — Cryostats, laboratory amplifiers, magnetic tape recorders, and photographic film handling facilities including processing.

k. Documentation Requirements — No special requirements other than experimental results.

l. Special Operating Constraints — No special operating constraints except as indicated in e.

m. Contamination Requirements — Cleanliness of sensors and viewing parts.

E. Policies and Procedures: It will be necessary to view specified ground areas at specific times. Flights at short notice will be required. Adequate power must be available.

F. User Community: National and international weather services and agencies that organize operations to cope with and control weather dangers and disasters.

G. Community Interface: Periodic conferences to ensure that procedures are responsive to needs. Telemetry to relay data to ground for real time communication with user groups.

H. Future Actions: Continued SRT support for high resolution spectrometers, radars, laser radars, and other measuring instrumentation; and for mathematical models to allow forecasting in areas of hydrology, pollution episodes and weather prediction.

APPENDIX E

A. Discipline Area: Meteorology and Atmospheric Environment Quality.

B. Sortie Payload Title: Zero-gravity Atmospheric Cloud Physics Experiments Laboratory.

C. Sortie Utility: The sortie mode is ideally suited for the conduct of this mission as it provides the necessary combination of relatively short term turnaround for conduct of the experiment and receipt of the results, accommodations for required volume and weight needed for the multi-experiment laboratory, availability of man to conduct experiments and the required levels of a near zero-gravity environment.

D. Requirements:

- Length of Flights — 5 to 7 day sortie missions.
- Orbit — No constraints on orbital altitude or inclination.
- Data Requirements — Data - Return from orbit of photographic, digital/analog magnetic tape records, astronaut log (voice record) of experiment. Voice communication with control station on Earth with TV coverage desirable.
- Role and Number of Personnel — One cloud-physics trained scientist/payload specialist required. Highly desirable to have assistance of one other payload specialist. Role is to conduct a series of cloud physics experiments, make necessary real time adjustments/decisions, and record results.
- Stabilization and Pointing — No pointing accuracy requirements; stabilization requirements are those which are adequate to maintain less than or equal to 10^{-3}g condition for periods of approximately 20 minutes.
- Power and Thermal — Approximately 200 watts peak power, 1 watt average operation power; 2 hrs/day average operation per sortie with occasional operation twice per day. Required Shuttle Sortie Laboratory ambient thermal environment, 10° - 30° C (cloud chamber internal environment will range from +35° C to -35° C).

- Weight and Volume — Estimated ≤ 225 kg weight for laboratory with volume approximately 0.9 m x 1.2 m x 2.4 m. Self contained facility except for power requirement.

- EVA Requirement — None.

- Correlative Measurement — None.

- General Support Equipment — Experiment expendables and supporting equipment not in basic laboratory estimated at about 22 kg and 0.06 m^3.

- Documentation Requirements — Minimum documentation consistent with assurance of experiment accomplishment. Exact needs to be determined.

- Special Operating Constraints — No operational constraints at present time; however, astronaut motion should be minimum during experiments.

- Contamination Requirements — Minimal, except inside cloud chambers which are an integral part of the experiment laboratory and, are therefore, controlled by the experiment.

- Other — Shuttle Sortie Laboratory accommodations desired to permit easy access. Early flight opportunity for single engineering demonstration experiments would involve about 20–45 kg weight, 80 watts peak power and 0.06 m^3 volume. Some experiments may require earlier activation (in the first 24 hrs. after shuttle lift-off).

E. Policies and Procedures: Establishment of a procedure is necessary for flexible and short-time turnaround approvals for repeated flights of the laboratory based on experimenter needs. The current Apollo type "man-rating" of laboratory and associated equipment is a maximum requirement. Continued desire and interest on part of NASA to sincerely exploit the shuttle sortie mode to conduct atmospheric cloud physics experiments as an added part of NASA's meteorology program is important.

F. User Community: International in scope and involves 100 or more cloud physicists and about 40 research organizations.

G. Community Interface: User community interface should be through direct involvement of users in the definition, design, construction and flight of the multi-experiment laboratory. Professional society presentation and publication of papers should be prepared on the subject, plus symposium/workshops should be conducted. Emphasis should be on the cloud physics user applications of the experiments.

H. Future Actions: Future actions necessary to implement this experiment on sortie mission includes a strong and viable SRT program to define in depth: (a) the atmospheric cloud physics multi-experiment laboratory and applicable experiments; (b) the conduct of the engineering demonstration experiments on early shuttle sortie flights or pre-shuttle manned flight opportunities to better define eventual laboratory requirements, and (c) the conduct of single experiments whenever practical to acquire earlier scientific data and enable potential experiments to understand merits of orbital experimentation in cloud physics. In-house NASA talents and resources should be fully exploited on this program. A study of the correlation between laboratory experimentation and remote sensing measurements of clouds so as to achieve desired weather modification inputs operationally.

APPENDIX F

A. Discipline Area: Meteorology and Atmospheric Environment Quality.

B. Sortie Payload Title: Test of Materials and Components for Advanced Sensors.

C. Sortie Utility: The shuttle sortie mode is well suited to permit the exposure to earth orbital environmental conditions and return for further study of components for proposed advanced sensors. The resulting cost savings by permitting the testing, for example, of sensor component performance where new natural or fabrication techniques are utilized is important to insure eventual successful operations of the sensor.

D. Requirements:

- Length of Flights — 5 to 7 day sortie missions.
- Orbit — In general, no constraints on orbital altitude or inclination. However, there may be instances when it will be desirable to duplicate a particular orbit, e.g., a sun synchronous orbit at a height of about 1678 km (to be used by TIROS N) to test the effects of the radiation belt on certain components.
- Data Requirements — Data-digital/analog magnetic records of component performance, astronaut record (voice and written notes) of experiments conduct and results achieved. Voice communicators will control station on Earth for interface.
- Role and Number of Personnel — One payload specialist required with training in test procedures and test objectives of material or component under consideration.
- Stabilization and Pointing — There may or may not be stabilization and pointing constraints. An example of the former would be the requirement to point a painted or optical surface constantly toward the sun (or toward the earth).
- Power and Thermal — Estimated power: peak, 75 w; average, 50 watts for 1 to 2 hrs. per day utilization. Occasional component test will involve continuous operation for period of three to five days to develop test data base. Sortie lab thermal environment acceptable.

- Weight and Volume — Weight estimate - 35 kg, volume estimate - 0.23 m^3.

- EVA Requirements — No EVA required. However, the capability to deploy a sample initially, to retrieve it later for inspection by a man in the sortie laboratory, and to repeat this sequence several times will generally be necessary.

- Correlative Measurements — To be determined.

- General Support Equipment — Plan is for each test to be self contained except for access to power inputs. However, probable use of sortie lab housekeeping facilities is envisioned.

- Documentation Requirements — Experimenter documentation (limited) plus minimum documentation to permit installation in sortie lab and conduct of test by payload specialist.

- Special Operating Constraints — None defined at this time.

- Contamination Requirements — Measurement of the outgassing environment around the shuttle will be necessary for interpretation of the results.

E. Policies and Procedures: Short time approval and access to sortie lab mission is highly desired for the success of this effort and to permit the utilization of acquired test data in an effective and economical manner. Apollo type "man-rating" efforts are the maximum possible requirement. Single point of contact and commitment on shuttle sortie flight assignment with assurance that the test will not be modified or deleted except for purpose of flight and crew safety.

F. User Community: User community involves 50 to 75 active sensor compoment design and development groups plus basic instrument research organizations.

G. Community Interface: Interfacing with user community should be through an announcement of available capability for this type of test, designating a focal point within NASA to coordinate and insure accomplishment of desired results.

H. Future Actions: Future actions required are:

- Decision by NASA that it will report and accomplish this type of test.

- Assignment of NASA focal point

- Development of rapid response procedure for sortie flight assignment.

APPENDIX G

A. Discipline Area: Meteorology and Atmospheric Environmental Quality.

B. Sortie Payload Title: Orbiting of Operational and R&D Satellites.

C. Sortie Utility: The orbiting of automated satellites utilizing a reusable space shuttle will be a more cost effective method on the long term than the use of an expendable booster for each launch. An important aspect of this concept is the general relaxation of weight and volume constraints afforded by the shuttle, thus permitting appreciable savings in the design and fabrication of spacecraft and sensory systems.

D. Requirements:

1. Length of Flights — Less than one day, e.g., only long enough to deploy the spacecraft in orbit or to place the spacecraft with additional stages in a parking orbit.

2. Orbit — The following orbits are characteristic of four representative satellites, currently under development or proposed for the next decade:

   a. NOAA Operational Satellites (prototype TIROS N, first launch 1Q1977)-Circular, sun synchronous, 1678 km.

   b. Geostationary Operational Environmental Satellite (prototype Synchronous Meteorological Satellite (SMS), first launch 4Q 1973)-Geostationary orbit, 36,000 km.

   c. Earth Observatory Satellite (EOS), (R&D, first launch 1Q 1978)-Circular, sun synchronous, 1000 km.

   d. Synchronous Earth Observatory Satellite (SEOS), (R&D, first launch in early 1980's)-Geostationary orbit.

3. Data Requirements — Minimal, only data pertaining to launch phase required.

4. Role and Number of Personnel — Only shuttle crew.

5. Stabilization and Pointing — Not critical (requires mission analysis).

6. Power and Thermal — Not critical (requires mission analysis).

7. Weight and Volume — (nominal):

   a. TIROS N-630 kg, 1.5 m x 1.5 m x 2.4 m.

   b. SMS-450 kg, 1.2 m x 1.2 m x 2.4 m.

   c. EOS-1730 kg, 1.8 m x 1.8 m x 7.6 m.

   d. SEOS-2350 kg, 2.5 m x 2.5 m x 6.1 m.

8. EVA Requirements — None.

9. Correlative Measurements — None.

10. General Support Equipment — Standard equipment required for orbital deployment.

11. Documentation Requirements — Standard requirements for orbital deployment.

12. Special Operating Constraints — None.

13. Contamination Requirements — Minimal, to avoid contaminating optical and radiation cooler surfaces.

14. Other — Both the staging and the delivery, servicing, and retrieval shuttle modes will be needed for these types of missions.

E. Policies and Procedures: A policy of effecting savings through the use of standardized or existing subsystems or components must be instituted to reduce the cost of research in space. This change in policy will be made possible by the relaxation of weight and volume (and, hence, power) constraints permitted by the space shuttle concept.

F. User Community — The user community primarily consists of NOAA, but also includes DoD, other government agencies, universities, foreign weather services and other agencies in many countries.

G. Community Interface — The existing interface with the user community has been developed over many years and is well established. However, steps should be taken continuously to improve these relationships.

H. Future Actions – Studies should be carried out to investigate methods by which the space shuttle can replace the expendable boosters currently used to orbit automated satellites and to explore the various cost savings afforded by the shuttle, such as the relaxation of weight and volume constraints, etc.

PRELIMINARY REPORT
OF THE
LIFE SCIENCES WORKING GROUP

CONTENTS

	Page
INTRODUCTION	8-1
DISCIPLINE AREA: LIFE SCIENCES	8-3
ORBITER IMPACTS	8-4
DESIGN REQUIREMENTS	8-5
RECOMMENDED POLICY AND PROCEDURE CHANGES	8-7
MAGNITUDE OF USER COMMUNITY	8-8
INTERFACE WITH THE USER COMMUNITY	8-8
RECOMMENDED FUTURE ACTIONS	8-8
APPENDIX A LIFE SCIENCES/SPACE BIOLOGY	8-A-1
APPENDIX B PLANETARY BIOLOGY	8-B-1
APPENDIX C BIOMEDICINE	8-C-1
APPENDIX D LIFE SCIENCES – ADVANCED TECHNOLOGY	8-D-1

PRELIMINARY REPORT
OF THE
LIFE SCIENCES WORKING GROUP

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INTRODUCTION

This is a preliminary report covering a broad area. It is a valuable overview of the potential payload density for life sciences in its broadest context. Time did not permit the level of detail or extent of description that would provide a second layer of information below that contained herein.

In reviewing this report, the reader must keep in mind that Tables 8-1 and 8-2 display a matrix of flight opportunities by category of life science research or technology and does not represent experiments.

Table 8-1

Payloads

CARRY-ON PAYLOADS	1979	1980	1981	1982
Life Support Systems	2	2	2	
Biology (Advanced Biopack)	2	2	2	2
PALLET PAYLOAD:				
Bioresearch Module	1 launched & retrieved 1 retrieved			

Table 8-2

Proposed Total Flight Schedule

SORTIE LAB 7/30 Days	79	80	81	82	83	84	85	86	87	88	89
BIOLOGY	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X
PLANETARY BIOLOGY											
Earth Orbital	XX	XX	XX	XX	X	X	X	X	X	X	X
Planetary	XX	4X	XX	4X	4X	XXX	4X	XX	4X	XX	4X
BIOMEDICINE											
Models	XX	4	4X	XXX	XX	XX	XX	XX	X	X	X
Man	15X	24	32X	40X	60X	60X	60X	60X	60X	60X	60X
ADVANCED TECHNOLOGY											
LSS/Protective Devices	XXX	XXX	XXX	XX	XX	X	X	X	X	X	X
Teleoperators	X	X	X	X	X	X	X	X	X	X	X
EVA	XX	XX	XX	X	X	X	X	X	X	X	X

NOTE: The above table represents the number of flight opportunities that could be used by the discipline areas listed and not the number of experiments.

The Panel has identified important constraints that the life sciences payload places on the orbiter with the hope that these constraints will be considered in the design of the orbiter. These were highlighted and placed ahead of all else, since the orbiter design is so close in real time.

DISCIPLINE AREA: LIFE SCIENCES

The Life Sciences Discipline is an aggregate of related research and technology efforts including planetary biology, biomedicine, biology, and advanced technology. It is a continuing program from which design criteria and technology development can be obtained whenever flight programs or systems initiate their design phase.

GOALS AND OBJECTIVES

- Continue the research directed at understanding the origin of life and the search for extraterrestrial evidence or precursors of life.

- Continue the biomedical research necessary to understand mechanisms and provide the criteria for countermeasures in support of manned space flight.

- Continue advanced technology development on life support, protective systems, and work aids to provide as near an earth atmospheric environment for man as possible--to provide him with protection from hazards of the space environment, optimize his ability to work in space, and to maintain his health.

- Continue the research in biology to investigate those mechanisms observed to have changed in space on man-models wherein the investigation cannot be done on man, and to study basic biological functions at all levels or organization (subcellular, cellular, system, and organism) influenced by gravity, radiation, and circadian rhythms; factors which are inherent in the space flight environment.

POTENTIAL CONTRIBUTIONS

- The 7/30-day shuttle offers Life Sciences an opportunity to explore and evaluate the essential SR&T for future earth orbital space stations, manned planetary explorations, and the search for extraterrestrial life.

- Skylab will not answer all the questions of biomedical concern, therefore, the 7/30-day shuttle will provide the first opportunity for follow-on studies.

- The shuttle offers the Life Sciences community the first opportunity to conduct basic biological research in a systematic fashion, capitalizing on the unique features of the space environment.

- The shuttle offers the opportunity to explore the utility of the space environment for the solution of terrestrial biomedical problems not approachable by other means.

- The shuttle provides a platform for the evaluation of potential Life Sciences applications in earth resources, public health ecology, the earth's ecosystems, and the delivery of medical services.

ORBITER IMPACTS

As a result of extensive discussion, it was determined that life sciences experiments placed the following constraints on the shuttle orbiter:

- A feeding system that will permit accurate determination of food and fluid intake.

- A waste management system that will measure urine volume and provide for obtaining samples.

- A waste management system that will determine the wet or dry mass of feces and the potential capability for obtaining samples.

- An environment as close to zero g as can be engineered into the system.

- A late access to the payload, since many of the life sciences' experiments are living systems and often need to be either placed into the payload late in the countdown or may need to be examined at a late stage.

- A satellite launch and retrieval capability.

- Many of the life sciences biological systems are vibration-sensitive, and a requirement exists for a detailed definition of the vibration environment in order to assess the contribution of vibration to the understanding of the biological experiment results and the role that vibration has played in the changes observed.

- The orbiter should serve as a launch platform for unmanned probes in support of planetary biology goals and objectives.

DESIGN REQUIREMENTS

(1) Length of Flights: Technology, biology, and medicine want 30 days or longer beginning with '79 or as soon thereafter as possible. Can use 7 days for Technology, Planetary Biology, Medicine, and Biology.

(2) Orbit: For majority of work, orbital attitude and inclination are not critical. For radiation research, polar flights or flights beyond radiation belts (free-flying satellites) are indicated.

(3) Data Requirements: Return of specimens, film, tape and records. TM of sensor (analog and digital), audio and video; bit rates and analog bandwidths are being determined.

(4) Role and Number of Persons in Orbit:

79, 80, 81	LS Mission Specialist Dedicated Scientist
82-88	1 LS Mission Specialist 3 Dedicated Scientists
89---	2 LS Mission Specialists 6 Dedicated Scientists

(5) Stabilization & Pointing: Requirements for antenna pointing for earth tracking; camera pointing for earth scanning.

$\leqslant 10^{-5}$g for biology experiments

10^{-3}g for medical and technology

(6) Power and Thermal: (a) Carry-on Payloads

Power	Thermal
Av. 100w	TBD
Peak 500w	

(b) Shared Shuttle Sortie Lab

Power	Thermal
Av. 2.53 Kw	3.21 Kw thermal
Peak 3.17 Kw	(based on 4 men using lab).

(c) Dedicated Shuttle Lab

Power	Thermal
Av. 3.92 Kw	4.60 Kw thermal
Peak 4.90 Kw	(based on 4 man using lab).

(7) Weight & Volume:

(a) Carry-on Payloads: (2 packages/payload)

Weight	Volume
300 lbs. (150 lbs/package)	30.0 ft.^{3} (15.0 ft.^{3} /package) (Dimensions examplary: 2 ft x 3 ft x 2.5 ft).

(b) Shared Shuttle Sortie Lab

Weight	Volume
14,200 lbs. (Including equipment, support subsystems, and "can".)	390 ft.^{3} (equipment volume only) Preliminary layout occupied a 14 ft diameter cylinder 22 ft long.

(c) Dedicated Shuttle Lab

Weight	Volume
23,400 lbs. (Including equipment, support sybsystems, and "can".)	876 ft.^{3} (equipment volume only) Preliminary layout occupied a 14 ft diameter cylinder 36.3 ft long.

(8) EVA Requirements: In Shuttle Bay for EVA Research.

(9) Correlative Meas.: On crewmen as available; housekeeping data, shuttle performance data, especially g and vibration.

(10) General Support Equipment: None

(11) Documentation Required: None

(12) Special Operating Constraints: Low level g requirements.

(13) Contamination Requirements: None

(14) Other: None

RECOMMENDED POLICY AND PROCEDURE CHANGES

Currently, there is no single management policy for Life Sciences experiments in NASA, and the Panel recommends the publishing of a NASA Management Instruction (NMI) which would establish the evaluation of experiment proposals, their selection and their management through flight and post flight data analysis, publishing, and reporting.

The Panel feels that the Shuttle Program Office should issue an AFO at the very earliest opportunity in order to solicit interest and response from the user community outside NASA and to permit the assembly of interested scientists to exchange essential information concerning shuttle payload experiment activities.

The Panel unanimously supports the policy of PI participation from experiment inception to post flight recovery, data reduction, and reporting.

Any procedural change which would bring the 30-day capability into the near time frame of shuttle operations is highly desirable to fully exploit the shuttle sortie mode for Life Sciences.

The Life Sciences Panel has identified a need for a dedicated laboratory early in the shuttle sortie mode which appears to be a highly cost-effective approach by virtue of the consolidation of experiments reducing the run-out costs of flying the experiments serially.

The Life Sciences' requirements identify a 22-foot requirement for the early (7-day) sortie lab and 36 feet for the 30-day lab. Attempts to engineer the Life

Sciences Laboratory requirements in less space will increase costs predicated on current off-the-shelf flight-qualified hardware used in integration studies over the past one and one-half years to identify dedicated Life Sciences Laboratory concepts.

Reducing documentation Q and A requirements, and associated evaluation test and training requirements, will help achieve the low-cost goal for the shuttle.

The use of common laboratory equipment and the reuse of equipment will amortize much of the initial cost of Life Sciences modules and laboratories.

MAGNITUDE OF USER COMMUNITY

Keeping in mind that Life Sciences encompasses many disciplines including Biology, Physiology, Microbiology, Biochemistry, Exobiology, Behavioral Sciences, Psychology, Human Engineers, Life Support Systems Specialists, Protective Devices Specialists; including environmental control, thermal control, bioinstrumentation and associated instrumentation with cabin environment monitoring; all make up the potential user community which reaches literally hundreds of thousands of scientists and engineers throughout universities, non-profit research organizations, and the aerospace and allied industries.

INTERFACE WITH THE USER COMMUNITY

In addition to the AFO recommended earlier in this Report, the Life Sciences Panel has established this particular subject as an agenda item for their next meeting.

RECOMMENDED FUTURE ACTIONS

- Establish this Panel with a possible expansion by 2-4 members as the single management group for the shuttle payload planning for the Director of Life Sciences, Headquarters, NASA.

- Have all other current and proposed shuttle payload planning activities under the auspices of this Panel.

- Formally establish this Panel and approve its request to continue meeting at the intervals necessary to effectively contribute to the goals and objectives of the shuttle sortie mission experiment activities.

APPENDIX A

LIFE SCIENCES/SPACE BIOLOGY

APPENDIX A

GRAVITATIONAL BIOLOGY

All forms of life on earth have evolved under the influence of earth's gravitational field. As such, various life processes (e.g., embryogenesis, growth, development, morphogenesis, regulatory mechanisms, etc.) may be considered to be gravity dependent. While we can study the biological effects of increase in gravitational fields on earth by centrifugation, we cannot produce extended weightlessness, although in some organisms we can compensate for it; for example, by use of the horizontal clinostat.

The accessibility to space environment provides us the opportunity and means of conducting biological experimentation in the weightless environment--one to which no organism in the earth's evolutionary history has been exposed. This new dimension for biological research can be significant at three levels: the intrinsic interest in how organisms react to the unique weightless environment; the immediate application of such knowledge to the welfare of man on long-duration space missions; and the definition and elucidation of the influence that gravity has exerted on the growth, development, and evolution of organism.

In considering the unifying principles that describe life as it is known on earth, the biologists are convinced that we deal with a single kind of life--that all known forms of life can be traced back to a common origin. In this sense, biology has until now been a provincial science, for we have studied one type of life in one group of environments, and our generalizations are based on this group of examples. Just as the planetary biologists have an opportunity to increase vastly our biological knowledge by discovery of an independently evolved life on other planets under different environmental conditions, so the space biologist may increase our understanding of life on earth by studying it in the weightless environment of space and extending this newly acquired knowledge for the benefit of mankind.

An in-depth study will be conducted on a variety of biological materials ranging from cells, tissues, seeds, plants, invertebrates, and vertebrates. This approach will fulfill the needs and desires of the fundamental biologists as well as supplement studies on man himself. Vital gaps in knowledge in human studies can be supplied best, or even exclusively, by studies on lower forms of life. Man is considered to be part of a biological continuance which extends from the simplest forms of life to man.

While the 7-day shuttle sortie missions will suffice for studies involving cell replication, embryogenesis and other early stages of life as well as those of activity, longer duration earth orbiting flights (e.g., 30 days or more) will be required for growth, development, morphogenesis, and life cycle studies in most cases.

BIOLOGICAL RHYTHMS

Many, if not all, living organisms on earth possess rhythmicities of one kind or another. There has long been a controversy as to whether these rhythms are controlled by internal cellular processes or external environmental factors. A multitude of experiments have been designed to resolve this fundamental biological question. Unfortunately, it has been extremely difficult, if not impossible, to control all of the terrestrial environmental variables capable of influencing biological processes. The shuttle sortie offers us the possibility of removing certain biological systems from virtually all of these terrestrial variables. By this means, it is hoped that experiments can be designed to resolve the question of intrinsic versus extrinsic control of biological "clocks."

To derive meaningful data, eccentric earth-orbital flights of relatively long duration (e.g., 30 days or longer) are required and eventually deep space probes may be required depending upon results of eccentric earth-orbital flight experiments. A variety of well-tested, reliable, test organisms (plants, invertebrates and mammals) will be used.

RADIATION BIOLOGY

The intensities of high-energy, high Z (HZE) particles in the space environment are of sufficient magnitude to pose a possible serious hazard for the crew on long-term space missions. Experimental data are needed to assess and define the biological implications of HZE particles and the combined effects of ionizing radiation and weightlessness for developing realistic radiation exposure guidelines and for providing protective and/or preventative measures and procedures against radiation hazards for long duration manned space flights. To understand the mechanism of biological action of high-LET HZE radiations, it is necessary and important to relate their physical measurements (dosimetry) accurately and precisely to biological damage at the molecular and cellular levels. For this reason, appropriate dosimetric capability must be provided to determine the trajectory, energy, and Z number of particles impacting biological targets.

While substantial effort is being made to determine and understand the biologic effects of accelerator-produced particles and the combined effects of compensated

gravity (using the horizontal clinostat) and ionizing radiation, studies in the space environment are essential because the HZE particles of concern are currently not available for ground-based investigation--neither do we have the means of simulating the weightless environment of space. A variety of appropriate biological materials (e.g., seeds, plants, invertebrates, cells in culture, mammals, etc.) will be used to investigate effects at the molecular, cellular and organism levels.

The exposure rates from HZE particles for a 270-nautical-mile, 55° inclined orbit and an earth-synchronous, 0° inclined orbit are estimated to be in the order of 0.05 and 0.1 rem per day, respectively. The maximum particle flux that can be expected at the respective earth orbital inclinations during minimum solar activity is estimated at 70 and 140 particles of $Z \geq 6$ per cm^2 per day, and 2-3 and 5 particles of $Z \geq 26$ per cm^2 per day. The estimated number of thindowns, which are of particular concern because of their intense ionization and severe damaging potential, for the respective earth orbital inclinations are 2-3 particles of $Z \geq 6$ and less than 1 particle of $Z \geq 26$ per cm^3 tissue per day.

It is anticipated from previous short duration (2-3 days) balloon flight and earth orbiting satellite experiments, that significant results can be achieved in 7-day shuttle sortie missions. However, longer duration earth orbiting sortie missions (e.g., 30 days) are highly desirable at the earliest possible opportunity for both the HZE particle radiation studies and the combined effects of radiation and weightlessness. For the HZE particle studies, earth synchronous, 0° inclined orbits (North-South pole orbits) and placement of the experimental package at minimally shielded areas of the payload carrier are desired to increase the number of HZE particle "hits".

APPENDIX B

PLANETARY BIOLOGY

APPENDIX B

EARTH ORBITAL PARTICLE COLLECTION FOR CHEMICAL (ORGANIC AND INORGANIC) AND PHYSICAL ANALYSIS

The shuttle provides a means of collecting particulate matter in space which may be trapped in earth orbit. The presence of organic matter in association with dust particles in space has recently been confirmed by radio astronomy. The types of molecules present, the mechanism of synthesis and stability of these organics are of fundamental importance to theories of chemical evolution and the origin of life. Direct collection of particles which are definitely uncontaminated by spacecraft outgassing and organics will be analyzed on recovery. A sampling device should be flown routinely in every mission.

PLANETARY AND INTERPLANETARY PROBE LAUNCH

The shuttle can serve as a launch platform for:

- Mars Launch Missions — Automated follow-on Viking-type missions, to study the planet in detail from the point of view of characterizing the planet's biology, geology, meteorology, chemistry, etc. Experiments can be designed based on Mariner 9 data and later on, Viking data. A shuttle launch makes possible larger scientific payloads and launches in years not feasible for earth-launched missions (e.g., 1980's to Mars), with existing systems. Affords two launches per year opportunity to Mars - '79, '81, '83, '85, etc. The duration of the program depends on data obtained in early missions. The shuttle ultimately also provides the means of returning Martian or other extraterrestrial samples to the earth - after appropriate quarantine in earth orbit.

- Jupiter Missions — Jupiter orbiters and/or atmospheric probes to study the organic chemistry of the atmosphere can be launched effectively from the shuttle. There are data indicating that organic molecules may now be synthesized in the Jovian atmosphere, and therefore Jupiter may provide contemporary evidence of chemical evolution in our solar system.

- Titan Missions — Titan, one of the satellites of Saturn, is large enough to have an atmosphere which is composed of methane. The surface of Saturn (unlike Jupiter) is cold enough that organic molecules synthesized non-biologically in the atmosphere, would condense on the surface. Analysis of this material by means of instruments landed on Titan can make a very real contribution to our understanding of chemical evolution and the origin of life.

- Comet Missions — Organic matter, which may be remnants of the primitive solar nebula can be seen spectroscopically in comets. Acquisition and analysis of the material in the tail of a comet can be done by a "fly-through" mission, launched from the shuttle. The nature and amount of organic material in comets is fundamental to understanding chemical evolution.

- Asteroid Missions — The asteroids may be the parent bodies of the meteorites, including the carbonaceous chondrites. The chondrites contain organic matter; however, all meteorites on earth have been subjected to various degrees of contamination. Analysis of uncontaminated meteoritic material could be accomplished by an asteroid mission, which can also tell us more about the origin of meteorites and the importance of such organic matter to understanding chemical evolution in the solar system and the origin of life.

APPENDIX C

BIOMEDICINE

APPENDIX C

MAN-RELATED STUDIES

The shuttle will provide new opportunities to study the effects of the unique environment of space on body systems. Work in this area will extend our inquiries into areas of concern which have been highlighted from previous flight programs. Investigation will be directed toward the determination of man's capability to adapt to the space flight environment as this will have an impact on his ability to perform as a crew member, worker, and investigator during near and long-term orbital flight, and eventually for planetary exploration. Specifically, it is anticipated that further work will be required on those organ systems which have been found to be influenced by gravity by previous flights; namely, the cardiovascular, vestibular, and musculo-skeletal systems. The effects of low earth orbital flights on biological periodicities, especially those affecting physiological systems, also need to be studied. Finally, it can be assumed that the increased complexities of flight missions and the increased frequency of such missions will raise questions concerning the selection of flight crew members, their inter-personal relations, and the effects of behavioral and physiological changes on the adaptability of the human operator to perform effectively in these missions.

Each flight, regardless of duration, affords an opportunity to gain new knowledge. The scope and magnitude of any investigations will increase progressively with time. A dedicated Life Sciences Laboratory is required to gather sound scientific evidence in order to explain the behavior of human body systems during long duration space flight.

Even though many observations on a large number of individuals are anticipated during a short duration of flight exposure, they are not expected to produce the data necessary to qualify man for long duration space flight. These initial observations, however, will have influence in the near term by verifying ground-based studies, and by providing information about fundamental mechanisms which are expected to be altered with long duration flight.

The on-going or continuous program will utilize animals as well as man, whenever possible. Animal models will provide information concerning basic mechanisms not easily determined in man. Such animal models would provide information in areas where measurements have not been developed for use in humans or would carry a significant hazard if utilized in man.

PHASE A

Initial shuttle flights will be confined to sample collection, hopefully utilizing all crew members (urine, blood, status monitoring). As many subjects as possible will be utilized in order to obtain a large pool of data and to establish statistically significant norms and verify ground-based data. The first available flights and all flights thereafter should be utilized. All samples will be analyzed in ground-based laboratories. The findings from these studies will influence the course of future work.

PHASE B

As the number of human subjects is increased per flight, the specific investigations on human bodily functions will be increased, using invasive and non-invasive methods. Data will be obtained on body systems known to be affected by the space environment (cardiovascular, vestibular, musculo-skeletal). Statistically, significant numbers will be needed in order to make valid judgments. Without a dedicated laboratory, however, the scope of research will be severely limited. These measurements will complement and validate animal models.

PHASE C

The multidisciplinary scientific objectives, the increasing numbers of crew members, and the mission durations projected for the shuttle era pose an associated series of new selection, health maintenance, and behavioral efforts. Increasing demands on the unique talents of man appear to characterize the shuttle flights. It is recognized within the scope of this report that the previous empirical or pragmatic approaches will not adequately provide for this new relationship of man to the mission. Informational and developmental requirements dictate that the resulting data base upon which decisions will be made must be of sufficient depth to permit statistical confidence for the future of manned space flight.

A laboratory dedicated to biomedical research is required for indepth human and animal studies in order to determine basic mechanisms of adaptation to space flight. It is anticipated that, at least, one dedicated flight per year, in addition to each flight opportunity, will be required in order to provide information to create realistic predictive models or design protective devices. It is strongly recommended that these functions be provided as early as possible in the program.

On the basis of the factors derived from the research activities, the need for countermeasures and the relative effectiveness of a given countermeasure proposal compared to another will be determined. The countermeasure study program is so structured as to produce the information necessary for definition of countermeasure approaches, their effectiveness, and proposed use. A laboratory will also allow the testing of countermeasures to prevent the physiological deconditioning that occurs with space flight.

APPENDIX D

LIFE SCIENCES - ADVANCED TECHNOLOGY

APPENDIX D

LIFE SUPPORT SUBSYSTEMS AND PROTECTIVE DEVICES

The NASA SRT program in the above referenced technology area is dedicated to developing regenerative life support subsystems and advanced protective devices for manned space flight. These advanced subsystems and devices are required for future manned spaceflight beyond the Skylab and shuttle sortie missions. (Ex: modular space station and manned interplanetary missions.) It is imperative that gravity-sensitive subsystems and processes associated with this technology area be tested in space prior to their incorporation into flight hardware. The shuttle sortie offers the only opportunity to perform these essential experiments. Some of these experiments can be shuttle carry-on experiments in the 1979-1981 time frame and the other experiments should be performed on 7 and 30-day sortie missions. The majority of gravity-dependent phenomena can be demonstrated on 7-day missions, but long-range degradation phenomena will require the 30-day flight. These experiments can be performed on a life science dedicated module or on a shared module.

The final design of a modular space station is scheduled for 1984. Therefore, the frequency of life support and protective device experiments is high during the 1979-1983 time frame and is decreased from 1984 through 1989. Flight experiments in this area are required beyond the 1984 time frame in order to test advanced life support concepts and advanced protective devices that have been developed due to increasingly stringent biomedical requirements for manned flight. (Ex: lower CO_2 partial pressure requirements.)

EXTRAVEHICULAR ACTIVITIES (EVA) TECHNOLOGY

Although experiments planned for the Skylab missions (e.g., M-509), will provide some of the information required to design operational systems to enable the astronauts to work effectively in space during EVA sorties, additional in-flight experiments are required to develop EVA technology more nearly responsive to currently projected EVA needs. The sortie module and the pallet area (after payload deployment) offer an excellent opportunity to evaluate advanced EVA maneuvering systems, tether devices, space tools, and other work-site devices designed to assist the astronaut in the performance of tasks during EVA sorties. Since EVA support is projected for all low earth-orbital manned missions, including early shuttle missions, continuing in-flight experiments to develop the EVA technology base and astronaut experience are required. Increased frequency (i.e., 2/year), is indicated for the 1979-1981 time period to reflect the urgency in improving EVA technology in the near-term to support early Shuttle missions.

TELEOPERATOR TECHNOLOGY

An experimental free-flying teleoperator system is currently proposed for use as a prototype or experimental system, deployed from the Shuttle in 1979, to study the utility of this type of system to support both early operational missions of the space shuttle as well as future earth orbital missions. The initial system will be used to demonstrate (or establish the feasibility of performing) some fairly simple teleoperator functions, such as visual inspection of the orbiter's thermal protective system. Initial and succeeding in-flight experiments and tests will demonstrate component technology performance; e.g., visual environment sensor and displays, define man-machine capabilities to perform tasks of increasing complexity, and provide the necessary experience and data base required to develop successful operational teleoperator systems.

Following initial in-flight experiments in 1979 or 1980, it is anticipated that one free-flying teleoperator mission per year will be required using a portion of the sortie module for the control station and a portion of the pallet to deploy and dock the free-flying teleoperator spacecraft. The sortie mode provides low-cost opportunities to evaluate advanced teleoperator subsystem technology and to resolve any man-machine problems that may occur in the space environment in a manner responsive to the needs of near-term and long-term manned space missions.

REPORT OF THE ATMOSPHERIC AND SPACE PHYSICS WORKING GROUP

CONTENTS

	Page
SUMMARY	9-1
INTRODUCTION	9-4
MAIN THRUSTS	9-4
MODES OF PARTICIPATION	9-5
CANDIDATE MODULES	9-6

REPORT OF THE ATMOSPHERIC AND SPACE PHYSICS WORKING GROUP

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SUMMARY

The Atmospheric and Space Physics Working Group identified broad objectives for the Shuttle era. Two sortie modules were identified which would make significant contributions in these areas, based on the documented requirements of scientists desiring to participate. Several modes of participation are clearly needed, some of which require closely coordinated observations from other research tools, with the Shuttle playing an important but not a solo role. Minimum cost is achieved by maximizing the use of multi-purpose common core instrumentation. Key headlines are provided on the charts which follow: commentary is provided in the text, and details are available in separate reports on the three candidate modules.

Atmospheric and Space Physics Objectives

1. Investigate the mechanisms which control the near-space environment of the Earth.

2. Perform plasma physics investigations not feasible in ground-based laboratories.

3. Conduct investigations which are important in understanding planetary and cometary phenomena.

Atmospheric and Space Physics

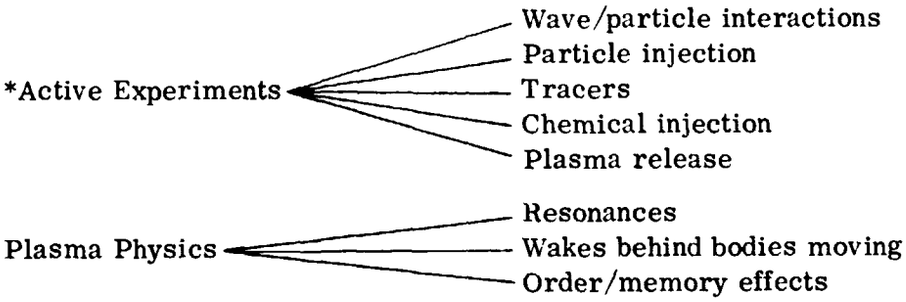
Shuttle features:

- 7-day duration tasks with core instruments
- Ability to perform active experiments
- One component of research project

Participation modes:

1. member of team making cause/effect studies
2. facility user
3. CV990 mode P.I.

Plasma Physics and Environmental Perturbation Laboratory



Plasma Physics and Environmental Perturbation Laboratory

156 scientist responses, 10 hr, 6 day, 36 missions to meet all proposed task requirements.

Core Instruments:

Radio	-Transmitter
	-Receiver
	-Spectrum Analyzer
	-Antenna Systems
Particle	-Accelerator/Injectors
	-Diagnostic Analyzers
Computer	

*Observe effects on ground or from other space vehicle-or vice versa.

Sub-Satellite

Booms

Data Management — intelligent combinations of on-board and on ground.

Atmospheric and Auroral Science Facility

Detailed studies of fluctuating phenomena

Observing platform for global dynamics

Diagnostic platform for observing perturbations

Chemical reaction/photochemical studies

Retrieval of collecting devices

Atmospheric and Auroral Science Facility

130 scientist responses to questionnaire with proposed tasks.

Facilities needed:

T. V. Camera (aurorae and airglow as well as trail observations)

Airglow Photometers/Spectrometers

Lasers — for chemical reaction excitation; backscatter

U. V. Sources

Release Canisters

Computer

Sub-Satellite

Booms

Data Management

Atmospheric and Space Physics

Conclusions

- Discipline has need for 2 distinct modules
  - Plasma Physics and Environmental Perturbations
  - Atmospheric and Auroral Science
- Each has enough tasks for repeated sorties
- Each uses core instruments plus auxiliaries
- Shuttle lab represents one tool-not self sufficient
- Most instruments need little development
- Continuing dialog needed with users/designers

INTRODUCTION

It is expected that the Shuttle will become available in the next decade. To make appropriate use of it then, it is important to forecast the background of knowledge which is expected at that time, and not to define payloads in terms of the needs of the previous decade.

It is anticipated that the earth's near-space environment will have been quite well explored and mapped, so that a fairly detailed picture will be available of the phenomena to be found, and the general nature of the variations expected with season, latitude, solar activity, etc. Inevitably there will be some gaps: it is, however, expected that these can be covered as needed, and that no massive data-gathering projects will be required.

MAIN THRUSTS

The summary objectives for Atmospheric and Space Physics are expected to be:

- Investigate the Mechanisms Which Control the Near-Space Environment of the Earth — This implies that phenomenological descriptions are available of features such as the magnetosphere boundary, the plasmapause, radiation belts, ionosphere, etc. The main thrust will be to determine unambiguously the mechanisms which control these features; so that, for example, the many variations of the ionosphere can be understood and computed in terms of the measured values of the solar input. Two approaches toward achieving such an understanding are available. In the

first, detailed cause-and-effect studies are made by measuring the interacting parameters over the region of interest. In the second, a known artificial perturbation is introduced, and the effects are observed. Both are areas where the Shuttle/Sortie mode can be particularly useful, via the two specific factors of a 7-30 day mission duration and a large payload capability. It must be clearly recognized that other components will generally be required for such investigations: the Shuttle can rarely perform all aspects of a cause/effect study by itself — most often it will need to operate in conjunction with interplanetary spacecraft, rockets, and ground-based installations.

- Perform Plasma Physics Investigations Not Feasible In Ground-Based Laboratories — Plasmas, at various concentrations, represent a major constituent of the Universe — an understanding of the physics of plasmas is, therefore, an important objective, and the Shuttle is capable of providing a laboratory platform for the performance of experiments essentially free from wall effects. This is particularly important for the non-linear effects which cannot be easily scaled. Examples are the wake effects produced by a body moving in a plasma, the interactions of an antenna at high power levels with a magnetoplasma, and the plasma memory effects. Use of the Shuttle as a diagnostic platform also falls under this heading: it is known that powerful ground-based transmitters can significantly perturb the ionosphere, but the detailed interactions are not understood, and overflights of a well-equipped Shuttle laboratory promise to provide a powerful diagnostic tool for such investigations.

- Conduct Investigations Which Are Important in Understanding Planetary and Cometary Phenomena — This category embraces a number of phenomena distinct from the solar/terrestrial relationship aspects of the first objective. For example, gaseous reactions which are believed to play important roles in the atmospheres of planets may be investigated. The release of gases thought to be major constituents of planetary atmospheres, the stimulation of reactions and the excitation of constituent species by use of lasers and other energy sources promise to provide powerful new tools for such investigations.

MODES OF PARTICIPATION

Three basic modes can be identified. Each is particularly suited for different purposes, and full provision should be made so that scientists may participate as most appropriate.

- Member of a Team Making Cause/Effect Studies — This is self-explanatory. Each team member undertakes responsibility for a specific portion of the task, some of which will involve work external to the Shuttle. For example, the injection of trace constituents from outside the magnetosphere in order to test theories of particle entry will require close coordination of the release, as well as diagnostic observations from the Shuttle, the ground, and at other carefully selected locations.

- Facility User — A shuttle sortie module equipped as a plasma laboratory with the proper core instruments will have the capability of being used for a wide variety of investigations. In this mode, the investigator uses the basic facility, supplemented with his own unique instrumentation if required, to perform his work.

- CV 990 Mode — In this mode, by close analogy with the Airborne research program, the investigator supplies his own self-contained instrumentation, not requiring core instruments, using the Shuttle for transportation. Power and on-board computer facilities should be supplied. In this mode, as in the previous mode, the Investigator may or may not be required to accompany his instrument on the flight, depending on the complexity of its operation.

CANDIDATE MODULES

Initial studies have been performed on three candidates:

a. Plasma Physics and Environmental Perturbation Laboratory

b. Atmospheric Science Facility

c. Space Shuttle Auroral Observatory

These are available, on request, as separate reports. Discussion indicated that (a) could fill up a large portion of a module, and could essentially stand on its own. (b) and (c) however, overlapped significantly, and could logically be combined. In addition, the provision of high-powered lasers and other exciters, as well as gas-release canisters, would provide the capability of examining chemical reactions, and contributing to Objective 3.

Two candidate laboratory modules were thus identified:

- Plasma Physics and Environmental Perturbation Laboratory (PPEPL)

- Atmospheric and Auroral Science Facility (AASF)

Further definition studies are needed to determine whether these should be separate modules, should be combined with each other, or should be combined with other facilities. Although the detailed design is in a very early stage for both facilities, it is important to underline that these represent the real desires and aspirations of 156 primary investigators and 130 scientists, respectively, who have submitted preliminary proposals. Both the PPFPL and the AASF represent multi-purpose research facilities with core instrumentation which can be used repeatedly for different tasks, thus contributing significantly both to important scientific objectives and to the prime directive of providing a mechanism for reducing the cost of research.

REPORT OF
SOLAR PHYSICS WORKING GROUP

CONTENTS

	Page
INTRODUCTION	10-1
RECOMMENDATIONS	10-3
REQUIREMENTS	10-7
SELECTION AND RESPONSIBILITIES OF SCIENTISTS	10-32
DATA MANAGEMENT	10-38
GROUND-BASED SUPPORT DURING MISSION	10-40
STANDARD FORMAT REPORT	10-42
APPENDIX A	10-A-1
APPENDIX B	10-B-1
APPENDIX C	10-C-1
APPENDIX D	10-D-1
APPENDIX E	10-E-1

REPORT OF
SOLAR PHYSICS WORKING GROUP

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INTRODUCTION

We started on a basis of what we feel are the scientific goals in solar physics and derived a number of ways in which the shuttle can meet the resulting requirements in the sortie mode. We did not consider the current details of the shuttle or the sortie mode of operation as sacred, but identified what we would like to be able to do, what demands this places on shuttle and sortie mode, and what needs to be done in the next months and years to get there from here.

The recommendations and supporting arguments in this report of the Solar Physics Working Group are intended as a basis for discussion; and will be reviewed, and revised where necessary, by an expanded Working Group with members from outside NASA. We hope that such a group can be convened in the near future.

We hope that the shuttle sortie mode will provide easy access for experimenters. It should be possible to get experiments onboard on short notice, such as in the "sounding rocket" mode described in the Requirements Section, and it should be possible to carry out exciting exploratory research including that developed by new research groups and students.

Solar physics can take excellent advantage of dedicated shuttle sortie missions as part of a balanced program of research by a variety of space and ground-based techniques. Some of the uses of the sortie for solar physics may be compatible with missions dedicated to other disciplines and should be considered also on that basis.

The Sun is an astronomical object, a star, but also has profound effects on the earth through emissions of particle and electromagnetic radiations. The study

of solar flares with space and ground-based techniques, and the observations of the propagation of the disturbances with orbiting coronagraphs and ground-based and space radio sensors, can provide the information needed to understand the mechanism of terrestial flare effects which are the subject of space physics.

Some of the instrumentation optimized for solar physics can be used for excellent research in other areas such as UV, X-ray and gamma-ray astronomy, planetary atmospheres, the earth's atmosphere, including the geocorona, magnetosphere, and pollutants; lunar libration point studies and perhaps others. A single research instrument built for all of these disciplines would not do a satisfactory job for any of them. Therefore, we take the approach of identifying other applications and recommend maintaining the option to use the solar instrumentation accordingly.

We did not discuss in detail what other discipline payloads might be compatible with the various uses of a shuttle sortie for solar physics. It is difficult to do so when the nature of candidate payloads from other areas is not well known. The solar physics users should be confronted with other users of the same specific sortie flight as soon as practicable so that the mutual interactions of the payloads can be discussed. Besides consumables such as power, data, time, astronaut-attention, weight, volume, and different orientation requirements in terms of direction and stability, there could also be other interactions such as effluents, mechanical impulses, scattering surfaces, etc.

The specific recommendations of the Working Group are contained in the next section of this paper.

The "Requirements" Section describes the scientific objectives, the instrumentation needed to attain them, and platforms which can accommodate it. NASA Field Center interests in the solar physics areas, and the role of man in the sortie mode, are also discussed. The related but separate issues of selection of experiments, the role of scientists during their design and construction, and their operation in space are the subject of the "Selection and Responsibilities" section. Data management, and essential requirements before and during the shuttle flights are discussed in the next three major sections. The last section with its five appendices constitutes the standard shuttle workshop report and references the other sections as needed. It also defines five modes of using the shuttle sortie.

Dedicated missions are strongly desired. The approximate order of increasing need for a dedicated mission among the modes in the appendices is C, A, D, B, E. Several identified modes can and should also be considered for missions dedicated to other disciplines.

The Shuttle Sortie Workshop has begun a dialogue between the shuttle designers and builders and the user community. This preliminary report continues this dialogue. While an expanded solar physics working group with representatives of the scientific community outside NASA will be revising this report, the shuttle designers should report the actions taken on our recommendations, make counter-proposals if necessary, and ask questions. It is imperative that this dialogue continue.

RECOMMENDATIONS

Shuttle for Solar Physics

The Space Shuttle presents exciting prospects for significant advances in space experimentation that will revolutionize solar physics and many other disciplines of space science. If properly planned and executed the shuttle sortie mode of operation will permit dramatic increases in the capabilities and return from platforms that will evolve from current programs and others that can be designed specifically for the shuttle and be first flown in the sortie mode. The Working Group urges that the NASA solar physics program make effective use of the solar activity maximum in 1979 for intensive flare studies, whether or not they are shuttle-based, if progress in understanding this important solar phenomenon with its multiple effects on earth is not to languish until the next activity maximum in 1990.

Role of the Scientist

- To assure participation of qualified solar physicists everywhere, NASA should operate as a national facility any sophisticated instrumentation in space which permits attack on a variety of solar physic[illegible]oblems.

- During the design and construction phases the primary responsibility for the instrumentation must rest with individual solar physics investigators, one for each major piece of instrumentation, to assure that the solar physics objectives are not compromised along the way. In return, the investigator(s) will receive an appropriate percentage of the observing time.

- The instrumentation, responsible investigators, and the users should be selected on the basis of open competition among the entire scientific community after a thorough scientific and technical review. The level of review should correspond to the scope of the mission.

Problem-Oriented Approach and Ground-Based Observations

The Working Group strongly recommends that a problem-oriented and coordinated approach be taken in the study of solar physics. Problem-oriented instrument complements should be given preference over integrated payloads with diverse solar objectives. Instrumentation with mode selection flexibility that can attack a variety of solar physics problems is conceivable and should be complemented with other instruments as required. To be cost-effective we recommend to fly only instrumentation that requires extended flight and to use ground-based observatories, sounding rockets, and other means to complement the shuttle mode of operation as required.

Instrument Development

We recommend that instrumentation be developed in parallel with the shuttle-in order that maximum compatibility and scientific usefulness be achieved. This includes effort on the development of large instruments that can already be defined but should emphasize the evolution of new types of instrumentation including new scientific teams as one means to increase the breadth of participation of the scientific community.

Examples include:

- High resolution imaging technology - visible, UV and X-rays
- Channeltron arrays
- γ -ray detectors
- X-ray film development
- Magnetographs

The Working Group urges that this be carried out and directed by scientists with adequate reviews by future users of the technology.

Science-Shuttle Interface

Since much solar physics may be done on the shuttle by experimenters placing various detection systems at the focus of the solar telescope facility we wish to resolve in this case, the question of where the interface resides. We recommend that the telescope or light-gathering devices be considered as part of the scientific instrumentation and be selected, built, and managed according to the guidelines set out in the Selection and Responsibilities section.

Contamination

Recognizing the sensitivity even of presently conceived instrumentation to contamination, and expecting greater sensitivity to contamination in future instrumentation, the Working Group finds the environment of the space shuttle as presently conceived to be totally unacceptable for shuttle based solar observations. It is therefore recommended with greatest urgency to positively eliminate all foreseeable sources of gas, vapor, and particulate contamination, both in the shuttle itself and in the environment which the instrumentation will see before launch. For example, a gas attitude control system and waste dumps are unacceptable. Electromagnetic interference is of similar concern.

Semi-automated Free Flying Solar Platform

This Working Group recognizes that progress in solar physics is most likely to result from an extension of the spectral coverage available from ground-based observatories to the UV, XUV and X-rays in space at comparable angular and spectral resolution, and to a coronagraph platform in space. It is therefore recommended to give highest priority to the evolution from the OSO-I, J, K spacecraft to a shuttle-serviced platform with equivalent capabilities plus interchangeability of instruments, increased data rates during solar transients, optional control from the shuttle and the ground, and a lifetime between shuttle visits of at least three months.

Small Shuttle Platform

It is recommended that an adaptation of sounding rocket operations and hardware to use with the space shuttle be vigorously pursued to:

- Provide for the lowest cost method for conducting Shuttle solar physics investigations.
- Overcome the present limitation in observing time.

This course of action is responsive to the strong recommendations of the astronomical community for a substantially increased effort and represents an exciting potential advance in this area which already is so attractive and fruitful.

Platform Development

Solar physics will eventually require angular resolution approaching 0.1 seconds of arc and will require a platform capable of supporting large and heavy instrumentation. The image stability must be at least as good as the angular resolution. It is recommended that a multi-disciplinary platform be developed that

can support any one of the solar instruments identified, and as many simultaneously as possible, and be made as stable as possible to reduce the cost and complexity of any image motion compensation within the instruments.

Verification Flights

The committee recommends that a vigorous program of verification flights, using balloons and sounding rockets, be established as appropriate to confirm critical design concepts and to define optimum levels of instrumental sensitivities.

Such a program will also provide initial indications of the types of data to be returned from the sortie missions and will thereby enable experimenters to prepare for the effective acquisition and analysis of the sortie data and will additionally represent significant research possibilities to help hold the experiment teams together as viable scientific groups while waiting for the sortie flights.

Quality Assurance

The Working Group recognizes that a drastic departure from present quality assurance requirements is mandatory if the shuttle sortie mode of operation is to be at all attractive, cost effective, and affordable. It is therefore recommended that the responsibility for scientific instrument performance be placed upon the builder of the instrumentation who will be motivated by his desire to obtain useful data and to get future flight opportunities, rather than by the need to formally document each step.

Data Management

In order to manage the very large quantity of data collected by a solar imaging device on the shuttle, we recommend that the following facilities be provided as part of the shuttle data management and communications system:

- On-board film processing
- On-board computing facility with image evaluation capability
- On-board video display driven by the scientific instrument or on-board computing facility
- Data relay spacecraft
- A dedicated channel for solar data and voice communications

- A method of retrieving all of the data collected by the payload such as on-board recording on magnetic tape.

We foresee a need to transmit all data for limited amounts of time. Normally the data transmission will be selective, but flexible.

On-board Displays and Data Bank

To provide man with the capability to recognize changes in the phenomenon of study, the shuttle sortie laboratory operational consoles must have a data bank available for recall, including strip chart recorders, and storage for image data, both hard copy and limited video.

Data Relay Satellite

To effectively use the shuttle sortie as an observatory, there is a requirement for an adequate communication (data) link between the on-board specialist and his ground-based counterparts. With the present limitations of ground station coverage the data rate requirements make it mandatory that a shuttle sortie dedicated data relay satellite be developed concurrently with the shuttle.

Orbits

Solar physics shuttle sortie missions can benefit greatly from high inclination orbits which allow continuous solar viewing (sun synchronous). It is recommended that this option be maintained.

REQUIREMENTS

SCIENCE

The scientific rationale for a Solar Physics Program on the shuttle is the same which in the past has led us to extend the frontiers of solar physics and which calls for expanding the program of space solar physics in the future. To attack the current solar physics problems we must put our instruments above the earth's atmosphere where they are free from the atmospheric absorption which limits the spectral range, free from the atmosphere turbulence which limits the sharpness to which we can define solar features, and free from the atmospheric scattering which obscures the corona.

For the solar physicist working on flares, space observations have enabled him to examine the energy spectrum of high energy particles originating in solar flare events, and provided the means to observe and analyze the evolution of a high temperature plasma associated with these events. Such observations have made it possible to describe the enhanced changed particle environment around the earth -- which gives rise to a variety of geophysical phenomena.

For the solar astronomer working on the quiescent solar atmosphere, space observations have demonstrated that energy losses from the lower corona by radiation and thermal conduction back to the chromosphere are comparable to those in the solar wind and conduction to space. The importance of these processes could not have been established without direct observations of the far ultraviolet solar spectrum. Based on scientific advances such as these, which are unachievable except through space observations, several advisory groups have in recent years presented coherent programs for the future of this discipline in space. Perhaps the most complete of these studies has been the report of the Solar Panel of NASA's Astronomy Missions Board (NASA SP-213) which showed how successively more sophisticated payloads could be used to provide fundamental information on the most challenging problems facing solar physics today.

More recently an augumented group of ATM experimenters has presented a plan for combining several experiments to concentrate on critical problems of the source of material in the corona, how the corona is heated and how the form of the corona relate to the underlying magnetic field and other indicators of coronal heating. Another group, based at the Aerospace Corporation but using information solicited from many solar physicists, has outlined the problems that could be attacked with a large solar observatory in space; and the instrumental performance required to achieve its objectives (Scientific Objectives and Instrument Performance Criteria for a Large Solar Observatory, E. B. Mayfield, et al., May 1972, The Aerospace Corporation, El Segundo, California).

In summary, these existing studies have emphasized that the most exciting progress in solar physics will be made by obtaining solutions to the questions of:

- How energy and material is transported, layer by layer, from the core of the sun to the photosphere, and then through a temperature minimum to create and sustain a hotter chromosphere and still hotter corona.
- How magnetism originates, evolves, and is distributed throughout the sun.
- Which physical processes are responsible for the 11-year cycle of solar activity, result in the formation of sunspots and prominences, and which produce the rapid conversion of some form of stored energy into the kinetic energy of relativisitic particles associated with solar flares.
- Whether solar abundances differ from layer to layer in the sun.
- The mechanism of solar flares and the transfer of flare energy to the earth.

Certainly, these challenging problems exist independently of the future course of space science. Our problem is to define how existing opportunities for space observations can be best utilized to advance our understanding in these areas. We therefore ask first, what are the potential research objectives that would benefit from:

- A short-lived shuttle mission (sortie)
- An extended mission

Secondly, we ask how the shuttle/solar payload systems should evolve in the shuttle program and in relation to other solar programs to provide continuity in the scientific investigations.

Finally, we outline the shuttle support systems and operational modes specifically required by the Solar Physics (Shuttle) Program.

We envision that the solar physics program on the shuttle will be an evolutionary program. It will build on the experience of earlier flights and contribute, at each step, to a demonstration of the effectiveness of the shuttle as a vehicle for research in space and of the role of man in making scientific observations.

In broad outline, we believe that the solar physics program on the shuttle will involve:

- Simple, self-operating experiments as well as those requiring sophisticated judgments and manipulations by scientists in space
- Single experiments operating independently of others as well as batteries of instruments designed to operate jointly in a coordinated program of research
- Existing instruments such as rocket payloads, which can make useful scientific observations given a longer observing opportunity as well as new instrumentation specifically designed to take advantage of the shuttle program
- Instruments which require only a small portion of the operating time of the shuttle as well as those which will require that solar observations represent a major fraction of the workload of a particular shuttle flight
- Experiments designed primarily to gain engineering experience or technical data (i.e., background in hard X-ray detectors or scattered radiation in EUV telescopes) as well as those making scientific measurements over extended periods of time

- Instruments which are "dropped off" by the shuttle, to operate on their own, as well as those which are man-attended and achieve their ultimate scientific usefulness by the use of man in interchanging scientific subsystems, repairing malfunctions and, returning photographic records.

The coordinated problem-oriented observing programs of the ATM experiments on Skylab constitute a list of typical solar physics investigations that can be carried out with a complement of instruments:

- Active regions
- Flares
- Prominences and Filaments
- Synoptic Observations of the Corona
- Quiet Sun Atmosphere
- Supergranulation
- Coronal Transients
- Solar Wind
- Chromospheric Oscillations, etc.

It is anticipated that Skylab will help us define the set of problems to be attacked with higher angular resolution such as is available on OSO-I, J, K, and is desired for follow-on instrumentation.

The current shuttle schedule, with the first flights beginning in 1978, is difficult to reconcile with the need for intensive studies of solar flares during the coming solar sunspot maximum (peak expected in February 1979). It is therefore of utmost importance that instrumentation oriented toward flare research be carried on pre-shuttle and early shuttle missions. Instrumentation such as X-ray spectrometers and polarimeters with no spatial resolution, and Bragg crystal spectometers with intermediate levels of spatial resolution (10 arc seconds to 30 arc seconds) but high spectral resolution, will take advantage of the large payload capability of the shuttle, while not imposing severe demands for absolute pointing capabilities. Such instruments also require a minimum of attention by the astronaut and could therefore be carried frequently as secondary science payloads.

INSTRUMENT AND TECHNOLOGY DEVELOPMENT

In order to make progress in understanding the physical processes in the solar atmosphere, the immediate goal of the solar physicists is a complete description of the physical conditions existing within a definable structure on the sun or associated with a definable event. This means a complete description of ion and electron densities, their distributions of velocity, as well as the magnitude and direction of magnetic fields for each position within the definable structure. Such data are needed regardless of the specific research topic. Once a particular problem is defined, however, the instrumentation can be made more specific, being limited to an optimum range of wavelengths, having time constants suitable for the phenomenon to be investigated, and having spatial resolution better than the size of the feature and, optimistically, better than the distance over which physical conditions change significantly. A typical set of instruments is presented in Table 10-1 from the Aerospace report.

Although we cannot now be certain of the ultimate instrumental capabilities which will be required, it has been demonstrated that improved spatial and spectral resolution improves our understanding of the phenomenon being investigated until the physical scale is reached.

The first step towards higher angular resolution than is attainable from the ground should be taken in the visible range where the solar flux is a maximum, and the need for improved angular resolution is clearly established. From a scientific point of view the largest aperture is the most desirable. A significant step can be taken with a 65 cm aperture where telescope technology has already been developed. A shuttle sortie flight of such a telescope with spectrograph, preceded by balloon qualification flights, is one of the most exciting immediate prospects.

The following are several specific observational goals which can be achieved by use of the shuttle. We envisage that on early shuttle flights the spatial resolution will be one to five arc seconds for most instruments. (This means that some existing designs such as those of OSO-I, J, K instruments may be directly usable.) Ultimately, the shuttle will be able to deploy a Large Solar Observatory carrying instruments in the 0.1-1.0 arc second class. It is highly desirable that all of the measurements in each group be carried out together in a particular shuttle mission.

Physical Conditions in the Quiet Solar Atmosphere

- XUV spectroheliograms in single spectral lines, 4-1500 Å
- Emission line profiles from point to point in each feature

- Vector magnetic field measurements from point to point
- Visible light images at very high spatial resolution (0.1-0.2 arc second) supplemented by spectra of photospheric and chromospheric structures

Physical Conditions in Active Regions, Flares, and Coronal Structures

- XUV spectroheliograms in single spectral lines from 1.5-1500 Å
- Emission line profiles in lines particularly excited in each phenomenon being observed, including nuclear gamma-ray lines.
- Magnetic field measurements with high temporal resolution (1 sec in a 10 point array as well as high spatial resolution)
- Visible light images in the Hα with high time resolution
- Spectra and polarization measurements of nonthermal emission
- Positional measurements of sources of hard X-ray emission
- Broad-band of XUV and soft X-ray filtergrams with good time resolution
- Hard x-ray spectral and polarimetric observations with good temporal resolution (0.01 sec per spectrum)

Optical, UV, XUV

Space flight solar optical instrumentation must meet progressively higher performance standards in spatial resolution ($\sim$ 0.1 sec), spectral resolution ($\gtrsim$ 0.01 Å) and optical throughput. Spectral coverage ranges from 1 Å up through the infrared. Simultaneous observations at selected wavelengths within this spectral range are required. A new class of space flight instrumentation, magnetographs, must be developed.

Impacts of these general requirements include:

- Co-Alignment of Instruments — In advanced instrumentation it is difficult to realize simultaneous observations in significantly different spectral regions because of the variety of optical designs required to efficiently collect energy for the sensors (crystal spectrometers, magnetographs, Rowland circle and Ebert-Fastie spectrometer mounts, coronagraphs, etc.) used in solar observations.

Table 10-1
Candidates for Solar Instrumentation of a Dedicated Mission

Instrument	Wavelength Range	Spectral Resolution $\lambda/\Delta\lambda$	Spatial Resolution (arc/sec)	Data Rate (BPS)*	Weight	Size (Meters)
Ultraviolet Spectroheliograph (normal incidence)	600-2000 Å		1.0	10^4	227 kg	0.5 x 1.0 x 3.0
Extreme Ultraviolet Spectroheliograph (grazing incidence)	100-600 Å	1000	1.0-2.0	10^4	136 kg	0.5 x 0.5 x 3.0
X-Ray Spectroheliograph	2-100 Å	1000	2.0-5.0	10^4	136 kg	0.5 x 1.0 x 3.0
X-Ray Telescope	(Broadband) 1-50 Å or 20-100 Å	3	1.0-2.0	10^7 (Video)	227 kg	0.5 x 0.5 x 3.0
Photoheliograph	>1000 Å	105	0.2(a)	10^8 (Video?)	907 kg with spectro-graph	1.0 x 1.0 x 4.0
Hard X-Ray Spectrum and Polarization Detectors	10-500 kev	3-5 20-30%	Full Disk	10^4	681 kg	1.0 x 1.0 x 2.0
Hard X-Ray Source Detectors	10-100 kev		2.0	10^4	91 kg	0.5 x 0.5 x 3.0

*Input to data buffers on spacecraft or to film image.

(a) To be achieved through short exposure times, assumes 1 arc sec pointing stability by spacecraft.

The significance of this co-alignment requirement may be considered as follows. When a fore-optical system such as a two mirror telescope is used in conjunction with a spectrometer or image recorder, one is primarily required to maintain the relative alignment of the mirrors. Even though a small residual misalignment may be experienced between the sensor and fore-optics, the effective boresight may be compensated for by calibration of the pointing off-set in orbit. On the other hand, two instruments, each instrument consisting of a set of fore-optics and sensors is far more complex. Correction of internal fore-optical misalignments and calibration of boresight off-sets between instruments is necessary but may not be sufficient. The severe spatial resolution requirements, ~0.1 arc second and limits on structural engineering in building static structures (that is, the limit of maintaining a fixed positional accuracy through launch and a varying thermal environment) indicate that adjustment of the total instrument package (boresighting) relative to each other in orbit must be considered as an additional design requirement.

- Common Object Viewing — Even though co-alignment techniques may be incorporated to achieve coincidence of instrumental boresights, it is not clear what criteria is to be used from the different sensors to affirm that the same object is truly being viewed by separate instruments. For instance, are x-rays emitted from the same spatial region (to within 0.1 arc second or better) as ultraviolet flux, exhibiting certain spectral features, and/or, are magnetic fields also to be associated with this point space or in the surrounding space? This may be the very information that the observations were to determine.

- Significant Object Location — Techniques must be developed to predetermine and/or quickly determine the location of solar features of interest. This is particularly important when the solar feature has a short lifetime. How does one quickly locate a very small object (~ 0.1 arc second), which has a short lifetime or significant decay history, on the solar disc before the object disappears and/or the object has proceeded significantly through its rise or decay lifetime?

- Calibration of Instruments — This is an extensive requirement covering mechanical and optical calibration including absolute photometric calibration. A great deal of laboratory research and development will be needed to solve instrumental calibration problems. In addition, the problems of calibrating space magnetographs must be investigated.

G

X-Ray and Gamma Ray, Neutrons

The objective is to acquire a comprehensive set of measurements on the characteristics of X-ray, gamma-ray and neutron emission from the flaring and non-flaring sun in order to obtain insight into the triggering mechanism of a solar flare, the total energy content of a flare (in conjunction with other measurements), and into the acceleration, containment and release of charged particles in the sun and during the flare. The characteristics in the photon spectral range of 0.001 to 10 MeV that must be measured to achieve this objective are:

- Spectral energy distribution in continuum and line radiation,
- Temporal history of the emission with a time resolution of better than one second,
- Polarization of the emission,
- Location of the emission in the solar atmosphere as a function of time and energy (this may be possible only for limb-flares).

The needed characteristics for neutrons are flux, spectrum, and time history.

The measurements will be of greater significance when compared with simultaneous radio spectral and spatial measurements and solar particle measurements. We anticipate that most of the radio measurements could be made from the ground, others from satellites which are in lunar or highly eccentric earth orbit.

Hardware

Table 10-2 is a terse description of the separate instrumentation packages that will required to meet the objectives.

Although these instruments should ultimately operate as a part of a solar flare problem oriented payload, a test of each instrument independently on the earliest shuttle missions would be highly desirable.

Because of the unpredictable nature of solar activity, the above set of instruments will have to be in orbit for a major part of the next solar cycle in order to secure a statistically significant sample of observations on the flaring sun.

Table 10-2

Instrument Type	MeV Energy Range	Required Pointing	Primary Measurement Objective	Weight, Power Volume, Telemetry
proportional counters and/or cooled solid state detectors	0.001-0.050	~5°	spectral (atomic line & continuum)	91 kg, 10 w 0.057m^3, 2 kbps
actively shielded scintillators CsI and NaI	0.030-0.600	~5°	spectral (continuum)	136 kg, 15 w 0.340m^3, 3kbps
actively shielded scintillators CsI and NaI	0.300-10	~5°	spectral (continuum)	680 kg, 20 w 0.850m^3, 3kbps
actively shielded cooled solid state device	0.100-10	~5°	spectral (nuclear line)	136 kg, 15 w 0.340m^3, 3kbps
Bragg reflection Li and Be scattering block polarimeters	0.001-0.005 0.005-0.030 0.030-0.200(?)	1°	polarization	136 kg, 15 w 0.340m^3, 3kbps
collimators - scanning or rotating Oda type or plain mechanical	0.005-0.200	better than 10 arc secs	location of X-ray source in solar atmosphere	136 kg, 15 w 0.340m^3, 3kbps
neutron sensitive scintillators	10-100(?)	N.A.	solar neutrons	227 kg, 15 w 0.765m^3, 1.5kbps

Infrared

Solar physics can profit from infrared observations in at least four areas:

- Infrared molecular lines can be used, for example, for abundance determination
- Infrared forbidden coronal emission lines can be used for the interpretation of XUV spectrum in terms of physical conditions in the corona
- Continuous emission such as in rare white light flares could be more frequent in the infrared and indicate the emission mechanism
- The far infrared continuum is important for the study of the chromospheric temperature minimum.

Instrumentation for these purposes is likely to be used intermittently for solar physics and be identical in concept to IR Astronomy instrumentation. The requirements of early IR solar physics are likely to be served by the occasional use of IR Astronomy Facilities provided the option to look at the sun is maintained in IR Astronomy instrument development.

The spectral coverage of high sensitivity instrumentation is generally determined by detector selection for a given spectral region and/or limited logistic support for cooled detectors. Broad spectral coverage is accomplished by selecting less sensitive detectors such as bolometers or thermally-sensitive pneumatic sensors (such as the Golay Cells). Temporal response characteristics of infrared detectors complicates the techniques of instrumental design in obtaining high sensitivity as well as broad spectral coverage. The shuttle sortie and/or resupply operational capability may open the way to perform observations hither-to rejected because of logistic limitations — particularly in the selection of cooled detectors.

Besides applying the techniques of double dispersion spectroscopy and/or multiple beam (FABRY-PEROT) interferometry to obtain high spectral resolution, the techniques of Fourier and Hadamard scanning instrumentation may be applicable for coronal emission lines.

Components

Individual components that require investigation include:

- XUV magnetograph polarizing/analyzing components

- Narrow band phase filters for use in the XUV and UV spectral region
- Low scatter, efficient diffraction gratings which can be used at fast focal ratios
- Low scatter surfaces for X-ray telescopes
- Alternate x-ray imaging techniques to achieve high throughput and spatial resolution. (Dicke, Baez, Wolter and Fresnel cameras.)
- Collimator for crystal spectrometer
- Crystals which can be used to resolve line profiles (1 to 20 Å spectral region)
- Large mirrors (up to 1.5 meter diameter) for photoheliographs
- High emissivity, low absorption coatings for photoheliograph mirrors

Instruments

The further development of instrument assemblies must be provided. Some candidate instruments are listed.

- Magnetographs: for use in the visible, UV and EUV region
- Photoheliographs: aperture 65 - 150 centimeters
- Coronagraphs, low scatter
- Normal incidence stigmatic spectrometers, 1000 Å to visible, 0.01 Å
- Grazing incidence spectrometers at high diffraction orders, XUV, 0.01 Å or better
- X-ray crystal spectrometers, high resolution, collimated

Miscellaneous Technology

- Maintenance of surfaces in coronagraphs, grazing incidence telescopes, etc. Free of dust and other contaminants.
- Maintenance of open window detectors through modular replacement-resupply conceptual designs.

Power Supplies, Interference

Development of effective means to eliminate electromagnetic interference between shuttle and experiments is needed. This includes development of standard power supplies for use with instrumentation of many disciplines, avoiding ground loops through conductive decoupling except for single point grounding.

PLATFORMS

Orbiting Sounding Rocket

The sounding rocket has historically provided one of the most rewarding avenues in space science research. It has been and continues to be the workhorse of discovery for many disciplines including solar physics. Sounding rockets have provided crucial space observations with these advantages:

- Short time from experimental concept to flight
- Rapid turnaround after refurbishment or modification
- Recovery of photographic data if required
- Low cost

The major limitation of sounding rocket investigations has been the observation time of only 3 to 5 minutes.

The Space Shuttle offers the exciting potential for extending the very successful sounding rocket approach in solar physics while maintaining its advantages and overcoming the limit in observing time. It will be possible with the shuttle to conduct sounding rocket type investigations with factors of at least 10 to 100 increases in data and observing time.

Other advantages of extending the sounding rocket approach to the shuttle include:

- Packaged instruments already exist and are continuously being developed for new investigations. These will be available for use on the shuttle for the cost of refurbishment and updating.
- Sounding rocket payloads are already flight-qualified for the shuttle because of their design and flight history.

- Commonality is possible for these payloads because of their modular nature and of their standard dedicated pointing system.

- A number of payloads could be carried up simultaneously. This permits investigations with several independent but highly correlated instruments or substitution in previously ejected units after recovery.

This approach will also respond to the continued urging of the scientific community and advisory groups for substantial increases in this area.

A modest development effort is not needed for the timely development of the capability for shuttle use, including:

- An extension of the SPARCS life by an increase in power (batteries or shuttle power) and control capability

- An improvement in the roll control of SPARCS over that provided by magnetometers alone.

- A comparative investigation of free flying versus attached modes, either gimballed or supported on a bearing.

For the future an improvement in SPARCS pointing stability from the current ± 1.0 arc second to possibly ± 0.1 arc-seconds is foreseen and feasible.

Semi-automated Coarsely Pointed Platform (OSO)

For the decade of the 60's, the OSO spacecraft series represented the pioneering effort in the field of solar physics. The highly successful series of spacecraft has contributed the majority of man's data and understanding of solar ultraviolet and x-ray radiation. The present OSO series (OSO-I, J, K) will advance man's understanding as measurements with much improved spatial and spectral resolution allow a more detailed study of solar flares and energy transfer processes within the solar chromosphere and corona. Its capabilities far exceed those of earlier OSO's, and represent the logical next step in solar physics. It is logical and cost-effective to utilize this specialized solar observing platform for the study of solar physics problems in the shuttle era.

The OSO spacecraft of the 70's is a platform which provides solar pointing and scanning to an absolute accuracy of 10 arc-seconds and a stability of one arc-second, the first platform to compare favorably with ground-based observations in pointing. The prime solar instruments are complemented by significant solar and stellar X-ray experiments which can be accommodated in the wheel. As an automated spacecraft, it has a design life in excess of one year.

In the shuttle era this platform is ideally suited to those solar investigations which require instrument up-dating and other astronaut services, but require observing the sun for periods of about three months which is far in excess of the duration of a single sortie flight. The shuttle program with its manned capability also offers an extension of OSO capabilities including the following five areas.

New Instruments — The most exciting and desirable prospect is replacement of prime solar experiment instrumentation as required by revised objectives or progress in the solar physics discipline. A modification to the sail structure would permit replacement of pointed instruments. In this way emphasis for solar observations could easily be changed from chromospheric to flare observations, etc. Many techniques for solar study require the use of short-lived detector systems and optical systems subject to orbit degradation. Replacement of such critical systems would be a logical task for manned maintenance of the science payload.

Addition of a central computer to the OSO-I, J, K class spacecraft would allow reprogramming of on-board data handling system so that widely varying instrumentation can be accommodated. The present OSO command and data handling system can readily be adapted for an on-board central computer.

Instrument Replacement and/or Repair — The manned capability of the shuttle could be utilized to replace failed spacecraft instrumentation, and thus extend the useful life of the observatory platform. A re-distribution of the spacecraft system hardware in the wheel would be necessary so that limited lifetime items such as batteries and tape recorders could be maintained in the shuttle bay "shirt-sleeve" environment. This modification of the wheel instrumentation would require utilization of several of the present five experiment compartments for spacecraft hardware since the present layout is congested and would not appear feasible for in-orbit maintenance. Wheel science instrumentation would occupy less space, to the benefit of the maintainable solar pointing platform.

Real-Time Operations — Instruments with resolution of several arc-seconds often require pointing by the spacecraft to specific regions of the solar disk. The selection of the region to be studied is made in response to the changing solar conditions. Operation of the present OSO's is limited to the ground contact time, about 10% of the solar viewing time. This means that pointing can sometimes not be up-dated in a timely manner to reflect the latest solar conditions. In most cases, a delay of up to two orbits (three hours) is the present operational constraint for changing pointing coordinates in response to changing solar conditions. Such delays are certainly undesirable in the study of some solar phenomena.

The manned shuttle capability could be used to monitor and up-date spacecraft and instrument pointing during the times the shuttle is supporting the OSO shuttle platform. Use of a CRT display of solar data would permit the selection by the astronaut of the optimum solar pointing coordinates and instrument mode of operation. The astronaut would also up-date the OSO observing program by command.

High Data Rate — Many present OSO experiments could benefit from a large data rate for the short duration of certain special solar phenomena. This is especially true of instrumentation being considered for the study of solar flares. The present OSO telemetry cannot support all such experiment operations, therefore, the shuttle could serve as an intermediate processing and storage station. For example, the astronaut could control special high data rate channels for experiments between the OSO solar platform and the shuttle in response to special events such as flares. This data could be re-formatted on the shuttle for later transmission, or stored on tapes to be returned to earth.

Cost

The cost of the present series of OSO experiment instrumentation is due to the long development time and high-quality standards necessary for an instrument with an orbital lifetime in excess of one year. If instruments can be replaced, there can be a relaxation of some of the quality standards and the necessity for lengthy qualification of experiment systems. This could reduce the experiment lead-time from the present three years to 18 months, more consistent with rocket payload times. This approach would reduce experiment costs by at least a factor of two for new experiments and much more for repeat instrumentation.

Large Finely Pointed Platform

The telescope and instrument systems that will be doing solar physics in the shuttle era will ultimately require image stability of the order of 0.01 arc seconds and accuracy of about 0.1 arc second. The pointing stability should be maintained as well as possible in order to minimize the need for image motion compensation in the individual experiment packages. A pointing control to fulfill these requirements would have to be a three axis control capable of guiding a 1,500 kg payload. Additionally, the system should be capable of slewing a distance of several solar diameters in a period of minutes with a settling time of ten seconds at the new pointing coordinates.

The pointing control should be capable of being driven manually (joy stick) or by computer control.

The requirement of 0.01 arc seconds stability is admittedly severe. It would seem prudent and acceptable to develop such a pointing control in steps, i.e., initial flights with 0.1 arc second stability followed by later flights of greater stability culminating in a 0.01 arc-second system. Note that image stability rather than pointing stability is required and is attainable by image motion compensation within the instruments. This is costly and makes instruments more complex than would be desirable. A trade-off must be made between platform stability and image motion compensation which will require a continuing dialogue between scientists, shuttle and sortie module designers.

Large Coarsely Pointed Platform

Large, coarsely pointed platforms will permit doing solar physics from the shuttle with instruments which observe solar flares with hightime resolution without regard to their location on the disc, and for those experiments which contain their own fine pointing controls (one should not move the whole shuttle to bring a fine pointing control within range of lock-up).

Such a platform should be capable of operating in an altitude-azimuth solar tracking mode within the constraints (unknown at this time) imposed by shuttle maneuvers. The platform should be able to point a 1360 kg payload to within one to two degrees or less of the sun and maintain this pointing for each orbit sunrise-sunset cycle.

The manner in which the large power, command and telemetry requirements are to be supplied to the 1360 kg of coarsely pointed experiments should be considered carefully. A slip-ring approach may not have sufficient capacity.

An alternative to a coarse pointing facility on the shuttle is to permit experimenters to fly their own coarse pointing controls. Such controls have been developed for balloon flights by several groups although the balloon environment does not have the same hard vacuum, thermal, and mechanical shock (launch) conditions as the shuttle. Tests on current balloon pointing controls would indicate the design changes necessary to produce a shuttle compatible system. Many new balloon pointing systems will be designed and built and flown between now and the first shuttle flights. It would seem wise (provided that expense and complexity are not prohibitive) to design and test these systems with shuttle use as a possible application.

Interdisciplinary Platforms

All four platforms could be interdisciplinary. The sounding rocket and semi-automated platforms are likely to be primarily solar and be applicable to other disciplines. The two large platforms may be developed as interdisciplinary

platforms from the start, but must be able to support the special requirements of solar instruments (continuous sun viewing, occasional high data rates, etc.)

CENTER CAPABILITIES AND INTEREST

Goddard Space Flight Center

The Goddard Space Flight Center possesses a broad spectrum of capabilities and interests in solar physics research that would be directly applicable to shuttle research. In experimental solar physics these capabilities span the entire course from conception of an experiment to collection and publication of the data from that experiment in orbit.

Recent expansion of the solar physics group has added considerable theoretical and ground-based solar research capabilities with interest in using and supporting shuttle observations.

The residence of the OSO program at GSFC over the past 13 years has produced a program management team that is highly skilled and successful in guiding solar experimentation into space, and which is well known to the majority of the solar research community. It would seem natural to have this management team continue to exert its good offices on behalf of the solar community in the shuttle era. (Let's not start at the bottom of the management learning curve.)

Lastly, the collection and distribution of solar physics data (from OSO) has been conducted at Goddard for as long as OSO has been in existence. With the advent of recent and more complicated OSO's the OSO Control Center has become familiar with data management, spacecraft maneuvers, command sequences and experimenter participation in solar observations.

This broad distribution of capabilities is equally applicable to shuttle solar physics. Its application is a policy decision that we hope to contribute to.

Ames Research Center

Ames Research Center has years of experience in meeting the needs of the solar physics community in sounding rocket investigations by providing complete payload support that includes hardware (pointing control, telemetry, separation and recovery systems) and integration services. This overall systems capability is well suited to meet the requirements of the recommendation on the Small Shuttle Platform.

ROLE OF MAN

Introduction

Space flight in general consists of three active elements: flight crew, ground support and control, and machine. To produce the best results, each of these elements should be allowed to do what they do best. They should complement one another in an efficient pursuit of mission objectives. The nature of the mission objectives and resources available logically determine the degree to which the flight is manned, ground controlled, or automated. In the following, this general philosophy is applied to determining man's proper role in solar observations during the shuttle era.

The operational space shuttle brings the observing environment near earth orbit right to the front door of solar astronomers. It is to be viewed as an application of our nation's investment in manned space flight capability, rather than only an extension, and no hesitancy should exist in stating how it can best be utilized to most rapidly increase our understanding of solar physics. When space becomes more accessible, both the functions of the personnel and hardware used in solar observations will become more like those of ground-based observatories. Man, ground, and machine can become tailored more to the pursuit of scientific objectives than to the execution of space flight operations and logistics.

In the following discussion it is assumed that the optimum combination of crew, ground, and machine capabilities can be realized in operating a large orbiting solar observatory. A few of the variables which determine how closely this idealized case will be attained are funding, instrument availability, weight and volume allocations, crew availability and capability, other uses of the total facility, time and duration of missions, spacecraft systems, attitude requirements, orbital height and inclination, and other operational parameters. Rather than attempt to guess at what less-than-optimum combinations of variables will actually exist for shuttle flights, the most profitable utilization of man in solar observations, making use of shuttle capabilities, is described. This provides a baseline which can be used to determine man's proper role when the actual less-than-optimum variable to force limitations.

In a large orbiting solar observatory, envisioned to be an extension of the ATM, man can generally contribute in three ways: as a solar observer, as an instrument operator, and as a technician. In smaller solar payloads his role will include some, but not necessarily all of these activities.

Man as a Solar Observer

How He Can Contribute

One important and challenging aspect of solar observations done from orbit is the opportunity for man to significantly increase the selectivity and scientific worth of the returned data by exercising his judgement. This opportunity stems from the fact that, unlike stellar objects, we are close enough to the sun to observe many small features in its atmosphere (some smaller than 1/2000th of a solar diameter). The intensity of radiation we observe from the sun is a strong function of location on the solar disc, time, and wavelength. Since observing instruments are optimized for high resolution in space, time or wavelength (we cannot approach the limits in all three simultaneously), decisions must be made on where to point, what instrument modes to use, and when to acquire data. Many of these decisions are best made on the ground after careful analysis of the solar state, instrument telemetry, film available (if used), crew timeline, and other constraints. Many of the decisions can be made before launch and incorporated into automated modes. However, a good number of them are best made "on the spot" by an observer monitoring some of the unpredicted variations of solar features in space, time, and wavelength.

It is clear that if the ground had all of the on-board controls and displays continuously available to them, there would be no need for an on-board solar observer. However, the present and projected coverage of the tracking and data network for low earth orbit provides far less than continuous coverage. Additionally, the bandwidths available for data transmission will usually limit the quantity of data flow to something less than that which is the optimum and desired. Perhaps most noteworthy here, however, is that the major objective of the shuttle is to make it relatively simple and convenient for man to travel into earth orbit, rather than to bring the environment of space to earth.

One of the most important tools for locating the most interesting targets on the sun will be a video or other picture storage capability that permits comparison between the real-time sun and its recent history, thus pinpointing centers of special activity and interest.

Some of the ways in which an on-board observer can introduce selectivity in space, time, and wavelength into the data are now mentioned. Many are an extension of the present ATM capabilities.

Selectivity in Space

The ground should specify the type of target and its general location which are likely to be most effective in meeting the objectives of the observing programs.

However, the time between specification and observation will most likely be of the order of hours, during which time the location of the most interesting parts of a feature can change as well as be shifted by differential rotation. The final "tweak" in pointing is best accomplished by an on-board observer who has both a good knowledge of the observing objectives and displays that provide meaningful spatial information in various regions of the solar spectrum. These displays could include a real-time video magnetograph and monitors in selectable XUV and UV lines, several x-ray spectral regions, tunable Hα and CaK, and white light. The capability to recall and compare with earlier data should be available. The pointing tasks could be to align the aperture of a spectrograph on a chromospheric network element, a prominence thread, a magnetic neutral line, spicules, a disappearing filament, or the most interesting magnetic configurations in an active region. When the spatial information is displayed on a television monitor, manual variation of intensity permits rapid detection of hot spots in active regions and flares and the location of peak magnetic fields. When a solar feature is observable only with on-board displays the crew may elect to alter the observing program.

Selectivity in Time

The flow of observing programs should be specified by the ground where it is easiest to analyze in detail the total observing objectives accomplished and the consumables remaining. However, data on the short time constant features of solar activity requiring high temporal resolution (flares and related events) will almost always be acquired during programs initiated by the on-board observer. The decision to commit to a rapid data taking mode involves consideration of factors such as the history and the data already acquired on an active region, the importance of the observing program to be interrupted, film remaining (if used), and most importantly, specific characteristics of the initial part of the observed transient phenomena. Hence, displays must be available which permit a rapid but correct determination of the true nature of the transient events. These include a real-time video magnetograph which can display the time rates of change of the longitudinal magnetic field in an active region, monitors which display the past and present values of solar radiation intensity in several X-ray spectral ranges and several radio wavelengths, and a tuneable Hα display. To make rapid but intelligent decisions on when and where to point and what instrument modes to initiate or terminate, the displayed data must be complete without being overwhelming. The OSO flights and the ATM missions will significantly aid in determining what information is most meaningful to display.

- Selectivity in Wavelength — The on-board observer can also introduce some selectivity in wavelength into the data. Filters can be tuned across absorption lines to obtain the most useful data in support of other observations.

A rapid and coarse scan of selected portions of the spectrum from a small region could be presented and compared with a "nominal scan" allowing identification of interesting off-nominal features or times. Such a display would permit the identification of specific solar features or events in space and time by their spectral signatures. This area will also be better defined by OSO and ATM data.

Man as an Instrument Operator

Between the making of the decision of what type of data to acquire and the instruments actually acquiring that data, a variety of operations must be performed. In a manned situation, most of them will be done through a control and display panel. Each operation taken individually is a straightforward and simple task but, when considered collectively, the total operation can rapidly become rather complex. The various types of individual tasks could include instrument power up, aperture door operation, mode selection, pointing coalignment of two or more instruments, focusing, issueing start and stop commands, use of backup hardware, following written or mental timelines, voice and written data logging, interpretation of instrument talkbacks, use of backup and malfunction procedures, and operation of supporting systems (electrical, thermal, attitude control, etc.) Man is especially well suited to fulfill this role of instrument operator because of his ability to screen and analyze data from many sources (displays, timelines, books, voice commands, etc.) and then actuate the controls of each instrument in the correct manner.

As was the case when considering man as a solar observer, the ground cannot be as efficient as an on-board operator because of the limited bandwidths and coverage that are available for data transmission. However, for routine types of data (i.e., synoptic) using automated modes, whose durations are of the order of the time between ground contacts, the ground can command modes with sufficient efficiency. Therefore, it is useful for the ground to also have a control capability, thereby permitting efficient utilization of the facility if it must remain unattended for appreciable lengths of time.

The operating modes of an instrument (a series of programmed aperture, detector and optical element configurations) should be automated if it is to be done the same way each time and sufficient information is available during instrument design. Or, ideally, the automated modes of each instrument would be controlled by a digital computer in which the parameters specifying the modes are erasable. Manual modes of operation should also be included to provide both a backup to the automated ones and maximum flexibility in observing programs.

Man as a Technician

- The Effect of the Shuttle — The shuttle sortie mission should provide ground support with a routine accessibility to the large solar observatory. Thus, the necessary personnel and equipment can be readily made available for many useful servicing operations. Of the three uses of man, observer, operator, and technician, the latter one should be most augmented in the shuttle era over what has previously been done. A related objective of the space program with the advent of the shuttle is to make space hardware less expensive and more like that used for similar ground activities. More off-the-shelf hardware should be used and critical components should be made accessible. A high probability of mission success will be achieved by making the hardware serviceable in flight rather than by using highly reliable but also highly expensive parts and extensive test programs. Space hardware design and the associated use of man as a technician should become an extension of well developed ground practices rather than something which is exotic and overly complex.

  A major step towards having accessible instruments is made if they can be worked on in a pressurized environment. The pressurized bay in the shuttle orbiter provides a location for the work of the technician and should be utilized.

- Specific Tasks — The uses of man can be put into several categories. First he can assist in the initial deployment, assembly and setup of the observatory. Although the instruments should be completely assembled and checked out before launch, some reconfiguration may be required after the instruments pass through the launch phase and are in the operating environment of a vacuum and zero-g. Some of this reconfiguration may require EVA. Anticipated operation includes removing launch locks from sensitive moving elements (mirrors, gratings, etc.), relative co-alignment of instruments, calibration, focusing and systems tests. Once the observatory is in operation, the technician would be available for standard maintenance and servicing, instrument recalibrations, coalignments, focusing, and film changeout (if used).

It must be pointed out that, strictly from the manned operation standpoint, the use of film rather than electronic imaging for data acquisition has some significant disadvantages. These can include the requirement for EVA or repressurization of the instruments, the associated use of consumables (atmosphere, observing time, crew time), additional hardware and procedures development, confinement to the launch and return weight and volume constraints, in orbit film fogging and lack of opportunity for a quick look at the data as provided by the near real-time return of electronic imaging data. The use of film is not to

be completely abandoned, but it should be clear that its use does cost a significant price to the total system (principal investigator, hardware developer, crew and support organizations).

Perhaps the most useful capability of the technician to be utilized is that of instrument upgrading and repair. Upgrading operations include replacement of detectors with more sensitive ones, replacement of optical elements with more state-of-the-art elements, and replacement of a total data acqusition system with an alternate system that allows science of current interest to be accomplished. Repair operations are required when hardware malfunctions occur. These operations should not be considered off nominal, but should be designed into the system. On the ground one would not build an expensive instrument, completely seal it up, and plan to discard it when a major malfunction occurred. Likewise, we should not plan to do this in orbital operations. The shuttle can transport a technician and equipment several hundred miles up to within just a few feet of a failed component. The design of the instrument must allow the technician to go the remainder of the way.

Critical and relatively low reliability components should be packaged in modular fashion to facilitate changeout, functionally similar to the modular plug in the design of modern computers and aircraft. In electronic systems, the modular approach should be carried down to only the small black box level and not beyond to the individual electronic components. System diagnostics should also be possible. In optical systems, the individual components (gratings, mirrors, and lenses) should be replaceable when required because of contamination or other degradation.

The combination of a well trained technician and accessible hardware will provide a long effective lifetime and versatile operation.

Required Capabilities of the Solar Observer, Instrument Operator, and Technician

The position of solar observer should be filled by a physicist or astronomer with several years of experience in solar physics. By flight, the solar observer should be thoroughly familiar with the scientific objectives of each instrument and the observatory as a whole, and the functional aspects of each instrument, the controls, and displays. It should be noted, however, that a capable solar observer is not necessarily trained to operate many instruments simultaneously. The ability to properly interpret solar displays and select optimum observing modes is usually acquired in a different manner than the ability to follow and execute many individual diverse operations. However, since it takes many years to become a good solar observer, but one can become proficient at operating a complex set of instruments in approximately a year or two at most, it is feasible

and desirable to train the solar observer as an instrument operator. The combination of these two roles is termed a flight scientist for this discussion.

In contrast, it is not desirable to combine the flight scientist's responsibilities with those of the technician in a large solar observatory. The technician should have an in-depth knowledge of the physical details of each instrument, a knowledge which is quite distinct and gained in a different manner than the functional knowledge of the flight scientist. He should initially have a demonstrated capability in working with complex equipment and instrumentation. Training should make him well skilled in the areas of assembly, setup, maintenance, component replacement, instrument diagnostics and repair.

Optimum use of a large solar observatory dictates nearly continuous solar observation. This is accomplished by having a high orbital inclination and/or altitude, and means other than gravity gradient torques to desaturate the control moment gyros used for stabilization (perhaps by the creation of a magnetic moment fixed in the vehicle to torque against the earth's magnetic field). The nearly continuous solar coverage should be matched by the nearly continuous presence of a flight scientist. Thus, three and perhaps four flight scientists should be on-board at any given time. This requirement can be loosened somewhat by having the ground carry out many of the routine observing programs over several hours of a 24 hour day.

The shuttle permits a technician to be present, with necessary equipment, and to perform repair and maintenance when required. Or, he could be a permanent member of the on-board observatory staff and have most of the hardware stored on-board which he would require. This decision depends upon the detailed instrument designs and requirements, and the shuttle sortie availability.

A degree of flight familiarization should be required of all observatory personnel. This familiarization is conveniently gained in aircraft flights, either zero-g aircraft or high performance jets. Regardless of one's capabilities on the ground, operation in a zero-g orbiting observatory is a new environment and one must be psychologically and physiologically at ease in order to perform effectively. Flight in high performance aircraft goes a long way toward providing the necessary confidence in one's own abilities and reactions and in flying hardware. It also provides necessary familiarization with physiological stimuli. Formal military flight school need not be a requirement but sufficient time as a passenger/pilot should be obtained before launch.

Man-Machine Interface in the Sortie Mode

One of the significant advantages of the shuttle solar sortie missions can be the presence of man, for assessment of the proper functioning of instruments,

preliminary data analyses and resulting corrections or alterations of observing procedures, maintainability of the instruments and supporting systems. There will be the potential to perform repair and manual adjustments of instruments in orbit. These functions can be performed only if they are designed into the systems including access to the instrument section of telescopes in a "shirtsleeve" environment. This will complicate the sortie lab and telescope interface. For the early missions with an on-orbit time of 7 days routine maintenance with the resulting drawbacks of temperature and pressure cycling may require excessive amounts of time. The required adjustment of the same instruments (insertion of filters and aperture masks) may still need to be performed through automated mechanisms in these short missions.

The required exchange of film cassettes may be accommodated in an EVA-IVA mode or through remote manipulators. A strong requirement will eventually be made for mission durations beyond 7 days (14-20 days) in which it will be desirable and advantageous to consider routine maintenance and updating of equipment by man. The possibility of retracting instruments into the sortie laboratory should be investigated for these missions.

SELECTION AND RESPONSIBILITIES OF SCIENTISTS

This section addresses the subjects of the selection process and the responsibilities of scientists. Data analysis and interpretation are discussed.

PHASES

We distinguish between the phases shown in Table 10-4 leading from conception of a mission to the end product: new knowledge. Selection and science responsibilities for each phase will be discussed.

Table 10-3
Phases in Selection of Experimenter, Instrumentation, and Users

I. Establish disciplinary (solar physics) objectives for the mission.
II. Define experiment package needed to attain them.
III. Select instrumentation.
IV. Design and build instrumentation.
V. Use of experiment package in space.
VI. Data analysis and interpretation.

PRINCIPLES

We accept these principles as basis:

- The goal is to gain significant new knowledge about the object of study (the sun).
- At all times avoid the appearance of, or actual, unnecessary compromise of the scientific objectives.
- Avoid conflicts of interest in the selection process.
- The ground rules may differ depending upon the scope of the project.

CONSEQUENCES

Principle 1:

- Instrumentation that is sufficiently flexible to permit a wide variety of investigations should be operated as a national facility to insure broad and efficient use of the data.
- Coordination of observations with complementary instrumentation in space and on the ground is essential if required by the nature of the object or study.
- Data analysis and interpretation are of paramount importance and must be adequately planned for and provided lest the entire effort be wasted.
- There should be technical and scientific descriptions enabling potential users of a facility to plan their own observing programs, interface successfully with operations, and reduce, analyze, and interpret the resulting data.

Principle 2:

- A single responsible scientist must control the entire design and construction phases. Different instruments may be so controlled by different scientists which then form a Steering Group.

- The observing program during the mission must be controlled, within mission constraints, by a responsible scientist.

Principle 3:

- There must be open competition for phases I through VI in some form.

- Individuals from institutions that compete for science, engineering, or instrumentation funds will not participate in the scientifi review of candidate payloads or instrumentation.

Principle 4:

- A sounding rocket with a few minutes of observing time will not be operated as a national facility.

- A large space observatory with a variety of instruments capable of multimode operation on a variety of targets can be envisioned only as a national facility.

- Intermediate scale projects warrant special arrangements, such as guest investigator programs.

SELECTION

We discuss three examples: the small (sounding rocket), very large (observatory) and intermediate (OSO) cases, see Table 10-4.

Phase III selection must not close the doors to instrumentation that attacks solar physics problems other than those envisioned in phases I or II so that imaginative new approaches are not discouraged.

Table 10-4

Selection Phases vs. Laboratory Size

Phase (from Table 10-4)	Very Large	Intermediate	Small
I.	Headquarters with advice from scientific community. No conflict of interest arises.		
II.	AFO or Steering Group	AFO and proposals	Proposals
III.	Headquarters with advice from scientific community. Conflict of interest to be avoided. Advice through Ad Hoc Committee.		Mail reviews
IV.	NASA subject to approval by scientist(s)	Scientists subject to approval by NASA	Scientist within constraints and subject to required approvals
V.	Science Steering or Users Group	Scientist or his Users Group	Scientist
VI.	Users	Scientist or his Users Group	Scientist

PROPOSED ROLE OF THE SCIENTIST

As one means for implementing the principles and their consequences we propose:

- Every instrument will have a Principle Scientist (PS). An instrument may either be a complete package (such as an OSO experiment or a Sounding Rocket payload) or a significant part of a package (such as a telescope, a spectrograph, a magnetograph).

- The PS is selected at the same time as "his" instrumentation on the basis of open solicitation and while avoiding conflicts of interest (phase III).

- The PS is responsible to NASA for the design, construction, and calibration of "his" instrumentation.

- The PS has exclusive rights to a portion of the observing time in space, not to exceed 40% in a major facility. In small single purpose "experiments" he has exclusive rights to all the data. In either case, he has the responsibility to arrange for transfer of reduced data to the National Space Science Data Center (NSSDC) after an agreed upon time of no less than one year.

- If he has exclusive rights to less than 100% of the observing time the PS will produce a user's manual specifically to enable other users to understand the instrumentation, plan and execute a research program with it, and to reduce the data to the point when they are interpretable in terms of flux versus direction, wavelength, and time.

- The PS will assist NASA in the selection of users for the "open" portion of the observing time.

- All users are responsible to NASA for effective use of their assigned observing time, prompt analysis and interpretation of their data, and publication of their findings.

- After the initial successful flight of the instrumentation NASA will have the right to make it available to users for similar or other investigations. The PS will continue to be responsible to NASA for the successful performance of the instrumentation and will, in return, retain rights to some percentage of the observing time. If for any reason he will not accept this responsibility, NASA will be free to select another user scientist to take his place.

DATA ANALYSIS AND INTERPRETATION

It cannot be the sole objective of any science mission with the shuttle sortie to fly scientific instrumentation and return good data from space. It would be wasteful and useless to do so unless the scientific analysis and interpretation, which served to justify the instrumentation as well as, in parts, the shuttle itself, is carried out with the aim to derive new knowledge about the object of study, the sun, and to look for applications for the betterment of human life.

Mission planning would thus be incomplete and risk total mission failure in spite of good engineering performance unless adequate steps are taken to see that the data analysis and interpretation effort will take place. These steps must include:

- Selection of experimenters who are capable of, and willing to, carry out this effort and will commit themselves to doing it on a timely basis.
- Provision for the funding of this effort, either by NASA, or by arrangement with other science funding agencies in this country or abroad. It is essential that this problem be recognized, assessed, and planned for as one of the first steps in mission planning prior to a commitment to flight.
- Arrangement of topical workshops before and after the mission, either through the professional societies, the experimenters, or the NASA Project Office.
- Insistence on timely publication and submission of the data to the NSSDC.

APPENDIX: SOME FALLACIES

"The objective of a scientific space program is to build, successfully operate, and return good data from scientific instrumentation in space."

Although all these activities are indeed necessary to achieve the goal and account for most of the cost, they are entirely insufficient until the data are analyzed and interpreted to derive new knowledge about the object of study.

"The scientists want national facilities. Therefore we no longer need principle investigators."

This is true only to the extent that a principal investigator who controls all of the data is no longer appropriate when there is a wide variety and great quantity of data. A scientist with the responsibilities of current principal investigators (NMI 7100.1) is still required before launch (see "Principles" and "Consequences" above). He

may be called something else (Principal Scientist?) and will have first call on a percentage of the data as scientific return for his investment of time and effort.

"The scientists should define their requirements, then let NASA design, build, and launch the instrumentation for them".

This procedure is difficult if not impossible in a standard development such as of a house for residential use. If applied to the development of an advanced research tool it would result in mediocrity of the instrumentation and therefore the scientific return.

DATA MANAGEMENT

The data requirements of solar physics experimentation aboard the shuttle will be substantial. The experiments that will require the greatest bit rates are those that make their observations by forming images of the sun at one or more wavelengths from the infrared to the hard X-ray region. Since much significant solar physics is now known to occur on a time scale of one second or less the problem is compounded by the need to encode a large number of high resolution images in a short period of time. Additional difficulty ensues from the need to evaluate some of these images in real-time or near real-time so that changes in instrument level settings and/or modes of operation may be made in response to evolving conditions on the sun. The near real-time evaluation of the solar images may be done by a payload specialist visually inspecting an electronic (T.V.) or photographic display unit or by an on-board computer loaded with an image evaluation program or by image transmission to the ground. It is also possible that a combination of all three techniques may be used at times. Use of photographic image recording implies the need for a film developing facility aboard the shuttle. Typical data requirements for several days of observation with a solar imaging payload (problem-oriented) are contained in Table 10-5 extracted from the Aerospace Corporation report (see "Science" under the Requirements Section).

The high data rates quoted in the above referenced table suggest that an on-board computing facility will be required to select and compact data for transmission to the ground. Also a data relay satellite would greatly aid in managing data and communications problems.

Post-flight data analysis will require the entire fund of data collected by the solar payload. This may be gathered on-board via the use of magnetic tape recordings and returned of course with the lander for delivery to the users.

Table 10-5
Typical Payload for Problem-Oriented Investigation of the Corona

Instrument	Dimensions, m l	w	h	Weight, kg	Power, W Avg	Max	Data Mode	Rate	Remarks
Coronagraph	3.4	0.7	0.9	410	30	75	Film Video	1,000 m 10^7 bits/sec	Image studies of corona
Photoheliograph	5.0	1.5	1.5	2500	215	250			Primary image for other instruments
Spectrograph-spectroheliograph	3.0	0.7	0.5	500	125	150	Film Video	100 ,m 10^7 bits/sec	Spectroscopy and magnetic fields
Extreme ultraviolet spectroheliograph	1.0	0.5	1.0	400	90	100	Video	10^7 bits/sec	Spectroheliograms, line profiles
X-ray spectro-heliograph	10.0	0.5	1.0	400	90	100	Video	10^7 bits/sec	High-resolution spectro-heliograms, filtergrams
Vector magneto-graph	0.5	0.3	0.3	30	125	150	Video	10^7 bits/sec	High-resolution magnetic fields
Filter camera and video	0.5	0.5	0.5	100	125	150	Film Video	10,000 m 10^7 bits/sec	Images in selected lines

The non-image forming solar experiments have data requirements as indicated in the instrument section. These experiments will also use an on-board computing and recording facility, data relay spacecraft and real-time decision making. However, the will not in general be as demanding as the imaging experiments.

GROUND-BASED SUPPORT DURING MISSION

GROUND-BASED AND LABORATORY ASTRONOMY

A strong program of ground-based solar astronomy will continue to be required even if the shuttle becomes operational, and even when a Large Solar Observatory has been placed in orbit. To solve solar physics problems it is necessary to study solar phenomena in all spectral ranges in which significant information can be obtained. This includes the important visible and near UV and IR radiations which are observable from the ground. It would not be cost-effective, productive or possible to put all of this equipment into space. Similarly, there is a continued need for theoretical and laboratory research on atomic and molecular quantities which are needed for the interpretation of data from space.

For example, spectroscopic studies to analyze hydrogen require line profiles of Lyman-α (1216 Å), Lyman-β (1026 Å), H-α (6563 Å) plus about three points in the Lyman continuum ($\lambda < 912$ Å). Clearly the H-α can be obtained from the ground at much less expense than above the atmosphere. The situation is the same for spectroscopic analysis of many atoms or ions of interest. Because of the wide range in wavelengths, the technology is completely different; and since essentially another telescope system must be used, it might as well be on the ground. A template is needed to match the observations and this should be H-α. A well-conceived control center is needed to provide real-time communication between the various observers.

The T(h) variation in the solar atmosphere is very steep and the temperature changes by over two orders of magnitude in going from the photosphere-lower chromosphere to the corona. The different regions naturally produce lines and continuum lying in the different regions of the spectrum. Thus, a complete physical picture of a section through the solar atmosphere requires detailed observations at many wavelengths including the traditional ground-based range. If the experiment package is directed to flare studies, the complete range runs from about 10 MeV γ-rays to tens of meter radio waves. Ground-based radio observations must be considered as an integral part of any shuttle-related ground-based effort.

One must avoid mistakes of the past such as studying a solar phenomenon in a restricted range of wavelengths whether from the ground or from space and attempting to construct a model. This perpetuates the schism that still exists between some of the traditional solar astronomers and space scientists. The attainment of solid scientific community support for shuttle-related programs will require involvement of the traditional, ground-based workers. Although there is no basis whatever for any suspicions of the scientific community against the shuttle such suspicions do exist. A commitment to a balanced program would help allay them.

SOUNDING ROCKETS

It is anticipated that a modest sounding rocket program will need to continue even after shuttle sortie platforms become routinely available. We can see at least two areas in which even unlimited shuttle flight opportunities are not likely to replace sounding rockets as a necessary part of a balanced solar physics program. Calibration of the instrumentation on a shuttle sortie, a free flyer, and certainly an LSO will be necessary for the interpretation of the data. In particular, absolute photometric calibration in the far UV will probably require sounding rockets with payloads that can be calibrated immediately before the measurement is made in space.

Unique solar observations are possible from sounding rockets that fly along with the moon's shadow during a solar eclipse. It is not conceivable that shuttle flights can carry out equivalent observations.

USER FACILITY

When sophisticated solar instrumentation is operating in orbit it will be desirable to have a central user facility which has adequate links with the orbiting facility as well as access to computers, ground-based solar telescopes, library, meeting and working rooms, etc. Such a facility might be located at or near a major national ground-based astronomy facility such as the Kitt Peak National Observatory where these requirements can easily be met, and where there is the opportunity to interface with scientists working in other but related disciplines.

B

STANDARD FORMAT REPORT

1. Discipline area

   Solar physics

2. Outline the goals and objectives for the discipline for the decade of the 1980's.

   See "Science" and "Instrument and Technology Development" under REQUIREMENTS section.

3. Identification of the potential contributions the sortie mode can make to specific discipline goals and objectives.

   a. Study of the quiet and active sun with angular resolution comparable with that of ground-based observations, days to 3 months with a problem-oriented payload. (See "Platforms" and "Semi-Automated Coarsely Pointed Platform (OSO)" under REQUIREMENTS section.)

   b. Explore sub-arc second fine structure and establish its physical significance. (See "Platform" and "Large Finely Pointed Platform" under REQUIREMENTS section.)

   c. Experiment with new types of instrumentation to explore new ideas and concepts in theory, observation, instrumentation, and technology. (See "Platforms" and "Orbiting Sounding Rocket" under REQUIREMENTS section.)

   d. Extend the sensitivity of high energy instrumentation to explore flares and hot regions in the non-flaring sun. (See "Platforms" and "Semi-Automated Coarsely Pointed Platform (OSO)" under REQUIREMENTS section.)

4. Descriptive title of sortie mission or missions required for each of the potential contributions listed in #3 above (not necessarily all different).

   a. Deployment and/or Service of an Semi-Automated Solar Platform

   b. Large Solar Observatory Technology and Verification Flight

   c. Shuttle Sounding Rocket Platform Flight

d. Large Coarsely Pointed Platform, Solar Flight

e. Large Solar Observatory

5. Descriptive titles of sortie missions for which requirements and characteristics are outlined in attached appendices.

a.
b. } same as 4.
etc.

6. Outline of the proposed total flight schedule of sortie and non-sortie missions needed to meet the discipline goals and objectives.

Entry in table is number of flights with reference to item 4 above and sounding rockets; for ATM, OSO, and Balloons it is a flight designation.

	ATM	OSO	4a	BALLOON	4b[5]	S.R.[6]	4c	4d[7]	4e
1973	A					15			
1974		I		A[2]		15			
1975				B[3]		15			
1976		J				15			
1977				C[3,4]		15			
1978		K				15			
1979			1[1]		1[3,4]	10	2	1	
1980			2		1	5	2	2	
1981			3		2	5	2		
1982			3		2	5	1		
1983			3			5	3		1
1984			3		2	5	3	1	
1985			3		2	5	3	1	
1986			3		1	5	3	1	
1987			3			5	3		1
1988			3		1	5	3	1	
1989			3		1	5	3	2	
1990			3		1	5	3	2	

Footnotes:

1. OSO-K spacecraft is updated in all 4a flights.

2. German Spectro-stratoscrope.

3. U.S. Photoheliograph.

4. With Spectrograph.

5. 4b flights lead to LSO (4e).

6. Sounding Rockets used for calibration, special events (eclipses) after shuttle is operational, provided 4c flights occur instead.

7. Most important near solar activity maximum. Approximately five small balloon flights per year are required for instrumentation development. These might be X-ray and gamma-ray astronomy or solar physics discipline flights.

APPENDIX A

APPENDIX A

A. Discipline areas

Solar Physics

B. Sortie descriptive title

Deployment and/or Service of a Semi-Automated Solar Platform

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4. p.10-42.

Sortie Mode would be preferred because:

- New instrumentation can be substituted in the spacecraft to attack specific solar physics problems. No need to build a new spacecraft every time, very low cost compared to new launch
- Instrumentation can be returned, updated, and flown again at little more than the cost of rocket instrument refurbishments
- Spacecraft consumables, components, can be replensihed, repaired, updated
- High data rates during solar transients
- Astronaut can operate the free-flying platform, do fine guiding, react to targets of opportunity
- Shuttle can serve as a ground-station, operation optional from the ground

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

1. Length of flights — Time required to update, repair spacecraft, exchange experiments, of the order of a few days. With operation optional from the shuttle or from the ground, the astronaut can operate it usefully for whatever time is available. Time between shuttle visits to the platform: three months nominal.

2. Orbit — Fully sunlit orbit preferred

3. Data requirements — 6,400 bps between platform and ground, same between platform and shuttle, preferably more. Command capability, including stored command, important.

4. Role and number of personnel in orbit — At least two persons, one a payload specialist, for substitution of experiments, repair of platform and replenishment of supplies. If operation from the shuttle, need a specialist trained in programming spacecraft computer.

5. Stabilization and pointing

   Provided by platform.

6. Power and thermal

   Provided by platform.

7. Weight and volume

   Spacecraft weight 1,000 kg, volume $8 m^3$

8. EVA requirements

   Retrieve spacecraft. Delicate operation.

9. Correlative measurements — Ground-based measurements, calibration sounding rocket, other shuttle platforms desirable (see other appendices)

10. General support equipment — Computer, data handling and storage facilities, means to perform above mentioned operations on the spacecraft. Capture and deployment device.

11. Documentation requirements — Document any problems in installation, servicing of instruments, spacecraft. Record all commands and programming of spacecraft computer.

12. Special operating constraints — No effluents of any kind from the shuttle while spacecraft may be exposed to them.

13. Contamination requirements — Freedom from contamination by effluents such as gas, vapors, particles, at all times during handling of the spacecraft or while it is near the shuttle.

14. Other —

E. Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space. Reduce Quality Assurance requirements. Handle instrumentation as for a scientific sounding rocket flight. The responsibility for making the instrument work rests with the scientist, he has the most to gain and lose anyhow. Don't attempt to control his procedures except if required for safety reasons (no explosives, etc.).

F. Brief description of estimated magnitude of sortie mission user community. User community is estimated to include 80% of the solar physics community in the U.S.A. and 50% abroad. This amounts to about 100 institutions with some 500 or more individual scientists, not counting engineers and observers.

G. Recommended approaches for interfacing with the user community. Advertise the opportunity to provide instrumentation to replace that on OSO-K; select two to five instruments, half pointed section sized, depending upon quality of proposals. Provide a fixed amount of money, initially negotiated, to the scientist and tell him to produce the best instrument he can for that amount of money. The best completed instruments that make a problem-oriented payload fly first. The scientist gets a portion, here about 40% of the observing time. The balance goes to guest investigators.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

1. The OSO Project should study the changes needed in the OSO-K spacecraft to implement its later use as the Semi-Automated Solar Platform.

2. Negotiate changes in the spacecraft contract to build maintainability, capability to exchange instrumentation and parts, in the OSO-K. The additional costs should be compensated for by relaxation of quality assurance on the OSO-K spacecraft and instrumentation in view of the planned shuttle visits to the spacecraft.

APPENDIX B

APPENDIX B

A. Discipline areas

Solar Physics

B. Sortie descriptive title -- Large Solar Observatory Technology and Verification Flight

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4, p. 10-42. Preferred over ballon because:

- No need to carry a vacuum system
- More time
- Not limited in spectral range
- Sortie mode is preferred for verification on flight because of the large load capability, sufficient time to test out instrumentation and return sample data, realistically simulate LSO operation, and return of the instrumentation to the ground for improvements.

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

1. Length of flights -- a few days minimum

2. Orbit -- fully sunlit preferred

3. Data requirements -- Photographic and digital data handling. Large transient loads, data compression some of the time. See Tables 10-1, 10-2 and 10-3 for estimates of rates. Note especially photoheliograph rate as first payload. Also see the DATA MANAGEMENT section.

4. Role and number of personnel in orbit

   Spans the whole spectrum of astronaut activities. See "Role of Man" in REQUIREMENTS section.

5. Stabilization and pointing -- See discussion in REQUIREMENTS section on trade-off against instrument complexity.

6. Power and thermal — Thermal. continuous sun viewing in fully sunlit orbit, otherwise intermittent nights with consequent transients. Power: several kilowatts peak. Average lower, trade off power versus instrumentation cost and complexity.

7. Weight and volume — for one instrument (see tables)

   Estimated 1000 kg, and 4 cubic meters.

8. EVA requirements — None in short flights, except if unexpected repairs becon.e necessary.

9. Correlative measurements — As Appendix A D 9.

10. General support equipment — Pointing platform, data link, power, command, video, control console, data storage.

11. Documentation requirements — Minimum. Record all operations of the instrument controls, time, orbital parameters, problems.

12. Specia! operating constraints — No effluents from shuttle while instrumentation is exposed.

13. Contamination requirements — No effluents from shuttle while instrumentation is exposed, gas, vapor, or particulate.

14. Other —

E. Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space.

   Same as Appendix A, E.

F. Brief description of estimated magnitude of sortie mission user community.

   Same as Appendix A, F, assuming several flights.

G. Recommended approaches for interfacing with the user community.

   Select principal scientists. He should have rights to 40% of the observing time. Ealance to Guest Investigators, see SELECTION AND RESPONSIBILITIES section.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

1. Develop instrumentation as prototypes of LSO instruments, full scale or scaled down, fly on sounding rockets and balloons in preparation for first orbital tests on shuttle.

2. First instrument is a solar telescope (see REQUIREMENTS section) for high resolution work. High resolution UV, XUV, X-Ray, IR instrumentation to be developed concurrently and flown next. Use 65 cm aperture telescope technology, begin development of spectrograph.

3. XUV and X-ray telescopes with spectrometers, development to be initiated.

4. Develop interdisciplinary fine pointing platform, feed back stability and pointing accuracy and other specifications so that trade-off with image motion compensation can be made.

APPENDIX C

APPENDIX C

A. Discipline areas

Solar Physics

B. Sortie descriptive title

Shuttle Sounding Rocket Platform Flight

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4, p. 10-42.

- Gives additional time, by factors 10 to 100 at least, over sounding rockets flight.
- Maintains, in principle, all advantages of sounding rocket operation such as ease of access, rapid turnaround, no documentation of quality assurance, ability to fly exploratory instrumentation, train students, etc.
- If several solar sounding rocket payloads are carried in one flight it becomes possible to use some of them simultaneously for problem oriented studies, or sequentially for evolutionary studies.

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

1. Length of flights one orbit to several days.
2. Orbit — No constraints, except altitude minimum depending upon payload
3. Data requirements — Limited telemetry, photographic film
4. Role and number of personnel in orbit — Depends upon whether free-flying or attached. One person should suffice. He would make final adjustments, if any, to instruments, load, and retrieve film, monitor performance, select modes in some cases, retrieve instruments, possibly prepare for second sequence of observations.
5. Stabilization and pointing

   Shuttle as stable as possible as base for pointing platform if attached, no constraints if free-flying.

6. Power and thermal — Power internal or shuttle, nominal. Payloads not normally built to take large thermal loads.

   Weight and volume — each sounding rocket class payload

   Weight 250 kg, volume 0.5 m^3

8. EVA requirements — EVA only if free-flying and recovery desired.

9. Correlative measurements — See Appendix A, D 9.

10. General support equipment — Standard small pointing platform. See Appendix B. D 10. Capture and deployment device if free flyer.

11. Documentation requirements — Minimum

12. Special operating constraints — Shuttle stable if attached, no effluents.

13. Contamination requirements — Don't expose payload to effluents, vapor, gas, or particle.

14. Other — Would like to be able to carry up six payloads or more in one sortie, but can utilize even a single payload. In that case one would want flights more often, but would lose the 3rd sortie advantage in item C. above. A total of 20 sounding rocket class payloads in solar physics are needed per year, 15 of them on the shuttle. Three flights of five payloads each were assumed in item 6 of the STANDARD FORMAT REPORT section.

E. Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space: It is mandatory that it be possible to fly any sounding rocket payload without further qualification requirements if the payload has successfully flown before, or has undergone the normal sounding rocket pre-flight testing and preparation. In that case, the cost for payloads is down to refurbishment plus any changes, often of the order of $50,000 or less. See also Appendix A. E.

F. Brief description of estimated magnitude of sortie mission user community. About 15 to 25 research groups in this country, with 100 or more individual scientists. Somewhat fewer abroad. This is the opportunity for new groups, the number of which is unpredictable.

C

G. Recommended approaches for interfacing with the user community.

Same as in present Sounding Rockets Program.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

1. Initiate studies on how existing pointing controls (SPARCS) can be used to support sounding rocket class payloads for periods of at least one hour between servicing. Identify any changes that may be needed.

2. Survey the scientific community to establish candidate payloads that can profit from extended observations periods. Identify candidates.

3. Determine if free-flying or attached modes are preferred.

4. Provide verification flight as piggyback on a larger mission of any kind, in the preferred (free-flying or attached) mode.

APPENDIX D

APPENDIX D

A. Discipline areas

Solar Physics

B. Sortie descriptive title

Large Coarsely Pointed Platform

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4, p. 10-42.

- Ability to carry large arrays of detectors, heavy instrumentation of an exploratory nature, into earth orbit, operate for some time, then retrieve

- Only opportunity to take advantage of the next solar maximum of activity (1979) with critically needed high sensitivity high energy solar instrumentation

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

1. Length of flights — a few days to indefinite, depending upon nature of instrumentation, research objectives.

2. Orbit — fully sunlit preferred.

3. Data requirements — depends upon instrumentation, see tables in REQUIREMENTS ction for X-ray, gamma-ray, neutrons.

4. Role and number of personnel in orbit — operate, service if needed, collect data.

5. Stabilization and pointing — requirements of the order of one degree, see REQUIREMENTS section.

6. Power and thermal — Thermal loads normally not critical, power usage heavy, must be traded against instrument sophistication and cost.

7. Weight and volume — Weight and volume comparable with HEAO instrumentation.

8. EVA requirements — Normally none, except to service.

9. Correlative measurements — as Appendix A. D 9.

10. General support equipment — large coarsely pointed platform, can be multi-disciplinary.

11. Documentation requirements — minimum, as Appendix B. D 11.

12. Special operating constraints - depends upon instrumentation, normally none.

13. Contamination requirements — contamination may be a problem in this area.

14. Other —

E. Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space.

Balloon class instrumentation must be acceptable without need for further documentation or quality assurance. See also Appendix A. E, C. E.

F. Brief description of estimated magnitude of sortie mission user community.

As Appendix C. F.

G. Recommended approaches for interfacing with the user community.

As Appendix B. G.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

- Initiate development of the platform as soon as possible.
- Encourage science community in high energy astronomy, solar or other, to save its HEAO and balloon payloads as candidates for early shuttle sortie flights.
- Start development of new detectors, collimators.

APPENDIX E

APPENDIX E

LARGE SOLAR OBSERVATORY

A. Discipline areas

Solar Physics

B. Sortie descriptive title

Large Solar Observatory

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4, p. 10-42. Sortie is not preferred over a free-flying platform, but may be used for verification flights for the entire observatory as well as for individual instruments (see Appendix B).

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

1. Length of flights — indefinite.

2. Orbit — maximum sunlit.

3. Data requirements — very high. Trade off data rate versus continuity of operation.

4. Role and number of personnel in orbit — several observers (payload specialists) could be usefully employed. Tasks described in REQUIREMENTS section.

5. Stabilization and pointing — Stabilization to 0.01 arc second needed for images. Can be traded between platform stabilization and image motion compensation internal to instruments. Pointing accuracy of 0.1 arc second required. Can be attained by slit-jaw displays and joy stick capability in the instrumentation.

6. Power and thermal — Power requirements large, including for thermal control. Can be traded against instrumentation sophistication.

7. Weight and volume — Weight and volume depends upon instrumentation used. See table in REQUIREMENTS section.

8. EVA requirements — to be determined. See REQUIREMENTS section.

9. Correlative measurements — ground-based, free-flying semi-automated platform, also see Appendix C, D.

10. General support equipment — to be determined, includes computer, data storage, film processing.

11. Documentation requirements — minimum recommended. See Appendix B. D 11.

12. Special operating constraints — no effluents while instrumentation is exposed.

13. Contamination requirements — no effluents of gas, vapor, particles.

14. Other —

E. Polices and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space.

See Appendix A. E.

F. Brief description of estimated magnitude of sortie mission user community.

Probably even larger than described in Appendix A. F.

G. Recommended approaches for interfacing with the user community.

Instrumentation must be developed under direction of principal scientists, one for each major piece. In return, he gets a percentage of the observing time, to be determined at 10 to 40%. Balance to Guest Investigators. See SELECTION AND RESPONSIBILITIES section. Central ground-based facility for interfacing users with LSO data, ground-based data, theorists, scientists from other disciplines, is desired. Preferred at Kitt Peak, Sacramento Peak or another major ground-based observatory.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

See REQUIREMENTS section. Instrumentation needs development in the laboratory now, prototype flights on sounding rockets, balloons, and the early sortie missions, full scale verification flights on the sortie, see Appendix B.

REPORT OF
HIGH ENERGY COSMIC RAY WORKING GROUP

CONTENTS

	Page
INTRODUCTION	11-1
PAYLOAD COST FACTORS	11-4
DESIRED FLIGHT CAPABILITIES	11-8
EXPERIMENT MANAGEMENT	11-10
RECOMMENDATIONS FOR FURTHER STUDIES	11-12
APPENDIX A HIGH ENERGY COSMIC RAY SORTIE LABORATORY	11-A-1
APPENDIX B SHUTTLE SORTIE INSTRUMENT PACKAGE	11-B-1

REPORT OF
HIGH ENERGY COSMIC RAY WORKING GROUP

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INTRODUCTION

The study of high-energy cosmic radiation affords a powerful means of probing the universe and aiding in our understanding of various astrophysical phenomena. Measurements of the energy spectrum, nuclear composition, charge spectrum and directionality of high-energy cosmic rays can yield valuable insights into the age and origin of the universe and of the elements. The cosmic-ray flux carries with it information on the stellar processes that are partially responsible for the origin of the elements. The mechanisms that are responsible for supernovae, pulsars, quasars, and matter and magnetic field distributions in the galaxy all contribute to shaping the observed particle fluxes. A study of the primary cosmic-ray flux can, therefore, help in understanding these mechanisms.

Over the past several years, the NASA scientific program has been highly successful in determining the properties of the cosmic radiation below about 10^{10} eV through the use of small satellites, sounding rockets, and high-altitude balloons. HEAO will extend these studies to 10^{13} eV. Studies at still higher energy will have to be done with very large instruments to adequately investigate these extremely low flux components.

The space shuttle will enable us to place large payloads above the atmosphere on a moderately quick reaction basis for 7 to 30 days and for up to one year or more on free flying satellites. It will allow frequent flight opportunities on a flexible schedule. It should also allow a wider variety of comparative and competitive experiments. The shuttle will provide for return of emulsions, plastics, film, etc., and will thus expand the range of possible experimentation. The shuttle orbits at low altitude and varying latitudes are ideal for investigating high energy cosmic rays.

SCIENTIFIC OBJECTIVES AND GOALS

The goals for the proposed shuttle missions follow:

- To determine accurately, from direct measurements, the flux of cosmic-ray nuclei and their charge spectrum from 10^{12} eV to the maximum possible energy (about 10^{16}eV).

  The charge composition of galactic cosmic rays, their energy spectra and their directional properties contain information about their propagation in the interstellar medium. Changes in the shape of the energy spectra or charge composition at high energies would have important astrophysical consequences relating to their acceleration and containment in the galaxy. The size and weight capabilities of the shuttle make it ideally suited to carry detectors for studies of this type.

- To determine accurately the electron and positron energy spectrum about 10^{10} eV.

  The shape of the high energy spectrum should provide important clues concerning the age of electrons, the source spectrum, the acceleration mechanism, the storage times and the distribution of cosmic-ray electrons in the galaxy. High energy electrons also provide information on the interstellar energy density of photons and magnetic field strengths. The electron-positron ratio as a function of energy, is important for understanding source and propagation mechanisms.

- To determine the isotopic composition of cosmic rays.

  The isotopic composition of the secondary cosmic rays is important in determining cosmic-ray age and production mechanisms as well as providing a measure of the source function and the distribution of interstellar matter. The isotopic composition of primary cosmic rays carries information about the thermonuclear element building.

- To search for anti-nuclei in the primary cosmic rays.

  A small number of antiprotons are expected to be created by proton-proton collisions in interstellar space. They can be interpreted in terms of cosmic-ray lifetimes and the galactic matter density. The observation of an antinucleus would imply the existence of antimatter stars, and would have profound significance regarding the nature of the galaxy and the universe.

- To search for anisotropies in both the nuclear and electron components of high-energy cosmic rays.

  At energies $\lesssim 10^{15}$ eV, where the cyclotron radii become comparable to the dimensions of the galactic structure, a measureable cosmic ray anisotropy should be evident if the sources are located in the galactic disc. Anisotropies in high energy electrons would tell us much about the location of nearby sources and interstellar acceleration.

- To investigate, with good statistical accuracy, the flux and charge spectrum of the very highly charged cosmic rays, from $Z = 30$ to $Z > 100$.

  These experiments are very sensitive to the presence of the Earth's atmosphere as well as requiring enormous collecting areas. Good experimental data will be important in understanding the synthesis of elements and the source and acceleration mechanisms. The abundance ratios of radioactive transuranic nuclei relative to the stable isotopes should provide a direct measure of the age of cosmic rays. A search will be made for elements heavier than those known on earth.

- To search for high-energy, neutrally-charged components of the cosmic radiation.

  Because our current understanding of the cosmic radiation leads us to expect that these particles should not be present with observable fluxes, their discovery would be of major importance.

- To search for theoretically-predicted elementary particles.

  It is possible that the failure to observe quarks and magnetic monopoles in the laboratory can be attributed to the nonavailability of sources of artificially accelerated particles of sufficient energy.

- To conduct investigations of the high-energy interactions.

  Measuring high energy cross sections, multiplicities, and elasticities would be limited to those experiments which are not feasible with ground-based facilities.

The above goals are the rationale for the future cosmic ray investigations. Below we will outline three modes of using the shuttle which together would allow us to achieve these objectives.

PAYLOAD COST FACTORS

The opportunity offered by the shuttle for decreasing payload cost should be fully exploited. The following ground rules were felt to be essential for keeping down the cost of high energy cosmic ray experiments:

- modular construction of flight hardware
- simple interface between shuttle and experiments
- repeat flights of experiments
- scientist responsible for development and qualification of experiment
- careful consideration of cost drivers and timely trade-off studies

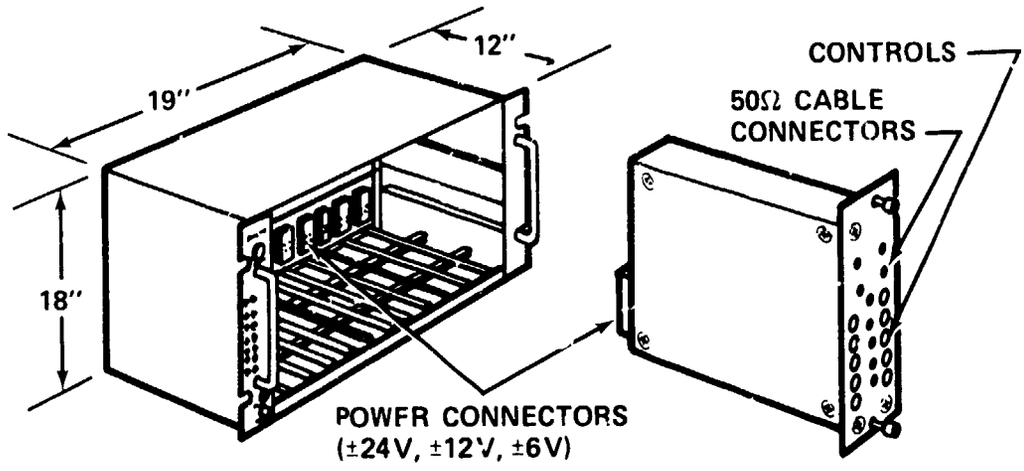
A discussion and the rationale for these ground rules follows:

Modular Construction of Flight Hardware

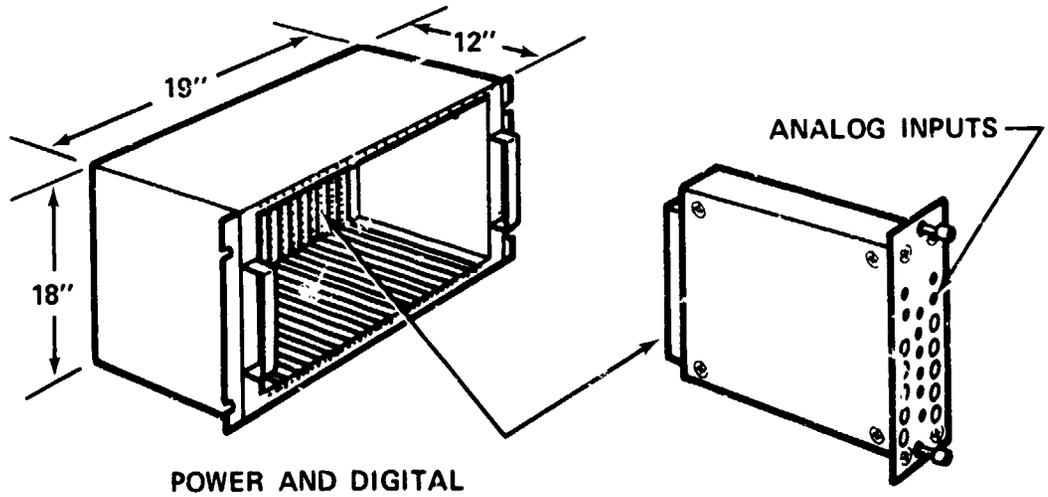
- Free flying and pallet experiments can be constructed of modules which bolt together and plug into an interface module.
- Electronics can be built up of standardized subsystems such as the Nuclear Instrument Modules* (NIM) now used in ground-based nuclear laboratories. A figure is attached showing NIM and CAMAC componets (Fig. 11-1). Industry will have to be encouraged to develop a low-power, space-qualified line as the power requirements of existing standard modules are too high. Qualification would be at system level rather than component level. Use of standardized modules should be encouraged. AFO's would require the use of standardized modules where applicable, and NASA might be able to procure the modules in bulk at reduced cost.
- Experiments would interface with computers for collecting and formating data through standard modular system like CAMAC. Experiment command and control would be through computer interface.
- Standard manipulators, EVA procedures, airlocks, etc., should be developed for servicing free flying satellites.

*Report TID-20893, Rev. 3

A STANDARD NIM RACK AND MODULE



A STANDARD CAMAC RACK AND MODULE



POWER AND DIGITAL
DATA CONNECTOR BOARDS
AND RECEPTICAL
(POWER ±6V, DIGITAL DATA IS 2 WAY 24 BIT
WITH EITHER MODULE OR COMPUTER
INITIATED DATA EXCHANGE. EACH MODULE
IS SEPARATELY ADDRESSABLE JUST AS
THOUGH IT WERE A COMPUTER CORE LOCATION)

Figure 11-1. NIM and CAMAC Components

Standard Interfaces Between Shuttle and Experiments

All experiments would connect to the shuttle through a standard interface module. The module would contain hazardous subsystems such as high pressure gas supply needed by a number of experimenters and would protect the shuttle against potential experiment problems such as an electrical short circuit. The following types of functions would be provided by this module:

- power conditioning
- standard mechanical interfaces to attachment points
- high pressure gas systems
- pressure container for experiments
- command capability, including computer capability if needed
- data handling

Repeat Flights of Experiments

In NASA programs utilizing balloons and sounding rockets, where repeated flights are available to an experimenter, the cost per experiment is considerably lower than in programs that offer only unique flight opportunities. Repeated flights of an experiment permit an orderly research program, optimum utilization of personnel, and a logical evolution of experimental hardware. In contrast, unique flight opportunities tend to lead to great sophistication of the hardware, an extensive test program, and redesign of standard subsystems for higher reliability and lower weight. The cost differential generally amounts to a factor of five to ten.

Scientist Responsible for Development and Qualification of Experiment

The simplest possible interface should be established between the shuttle and the participating scientist. The investigator should be responsible for the success of his experiment, and, in general, he should be in complete control of the design and construction of his hardware. Acceptance testing would be limited largely to simple acceleration, vibration and functional tests prior to launch. Shuttle safety would be insured through an interface module, the use of well-tested standardized subsystems where hazards are involved, and special operational procedures if necessary.

Careful Consideration of Cost Drivers and Timely Trade-Off Studies

The committee considered several items which will affect experiment cost, but additional studies will be required to assess fully the optimum tradeoff between alternatives.

- Safety considerations and use of man in space versus automation: Cosmic ray experimenters are used to working with automated instruments in the sense that man controls them remotely. A good analogy to shuttle sortie operation can be found in today's low cost balloon flights. Here the experimenter works with his equipment up to the time of launch, operates it remotely for the duration of the flight, and then recovers the equipment. In a seven to 30-day sortie, many advantages would be gained by manned control and operation in space. However, equipment must be man rated to insure the safety of the operator and large costs could be involved. Such additional factors as time line, training, and scheduling of the mission specialist become important, clearly limiting and restricting flight opportunities and turn around time. Thus, the preferred mode of operation may be to standardize interfaces, remove man's interaction to the shuttle cabin, and minimize specialized training and operator time. The scientific team on the ground would be kept informed through a telemetry link and would effect most of the control of their equipment by reprogramming the computer on the shuttle.

  A manual for experimeters which would tell them how to design for shuttle safety would be of particular importance. Statements like "NIMS logic can be used", "pressure vessels tested to twice operating pressure are acceptable", and "design for 4g static loads" would facilitate their design tasks. They would be trusted to follow these rules, subject only to simple acceptance tests, before integration into the shuttle.

- Sortie Laboratory Module: Man's presence in the module will be a large cost driver. For our purposes, a shirt sleeve enviroment for the equipment should be emphasized rather than for man. Man might enter only when the equipment was turned off. He could have his own life support rather than depending on the module for it. This mode of operation would minimize the risks involved in operating equipment such as superconductive magnets, thin-window high-pressure counters, and using thin windows in the skin of the sortie laboratory. In view of these considerations, it may not be cost effective to use the generalized sortie laboratory module that was described at the meeting. We recommend studies of the cost tradeoffs between a single all purpose sortie lab module versus designing individualized modules which satisfy only the subset of the requirements appropriate to one or a few disciplines. The tradeoffs between standardized

versus individualized versus weight versus power have not been studied sufficiently at this time.

- Use of Electrical Power and Temperature Control: Standard laboratory equipment uses a great deal more electrical power than the equipment normally used in space; a factor of over 100 is not unusual. It is not clear whether the cost saving possible by the use of laboratory apparatus is not counter-balanced by the additional cost of providing the required power and cooling. It may, therefore, be preferable to develop standard, low-power, shuttle-qualified equipment and maintain the option of using some laboratory equipment to meet special needs.

DESIRED FLIGHT CAPABILITIES

In planning the experimental program, three different uses of the shuttle capability have been envisioned. These will be outlined here and discussed in detail in appendixes. The cost considerations discussed above and the possibility of multiple use of shuttle missions dictated the details of this program.

Free Flying Cosmic Ray Observatory

A free flying module of 30,000 to 40,000 kg is required for long-term observations; it would be built up and maintained by twice yearly additions, deletions and refurbishment. This laboratory would be a national facility which could be used for a wide variety of cosmic ray and related measurements. It would be designed for experiments to look at rare components of cosmic rays with very large area detectors (10^2 to 10^3 times the area of HEAO cosmic ray detectors).

This satellite might be gravity-gradient oriented and could be combined with observatories for X-ray, gamma ray and infrared astronomy. It could be built up of modules which could be "piggy backed" on shuttle sortie missions for other prime users, or this satellite could be launched whole.

Cosmic Ray Sortie Laboratory

A laboratory containing a superconducting magnet would have wide application for sortie missions. Manned operation from the shuttle console would be required for charging the magnet and monitoring its operation. The 20 ft. long, 5,000 to 10,000 kg module would utilize about one third of the capability of a sortie mission in terms of weight and volume. It would be a pressurized can that could be entered safely by man only in a "power off" mode. The module probably would be operated at one atmosphere of nitrogen, with a shirt sleeve enviroment for equipment but not for man. On orbit, about 1 kw of power

would be required. One payload specialist would spend approximately half time on this equipment and could be shared with related experiments. Two flights per year, in approximately 55° inclination and 28½° inclination orbits would be optimal. This lab is illustrated in Figure 11-2 and described in Appendix A.

Shuttle Instrument Packages

Many cosmic ray experiments can be done with relatively small, self-contained instrument packages, which are connected to a single data processing and control unit. Up to six experiments in the few hundred to few thousand pound class would be mounted in the shuttle bay, probably on a pallet platform and fly ıor six to 30 days. The interface with the shuttle would be minimized so that the experiments could be flown on a "space available" basis. Scientists would find quick turn around, monthly opportunities, and reflight possibilities, attractive features. Power of

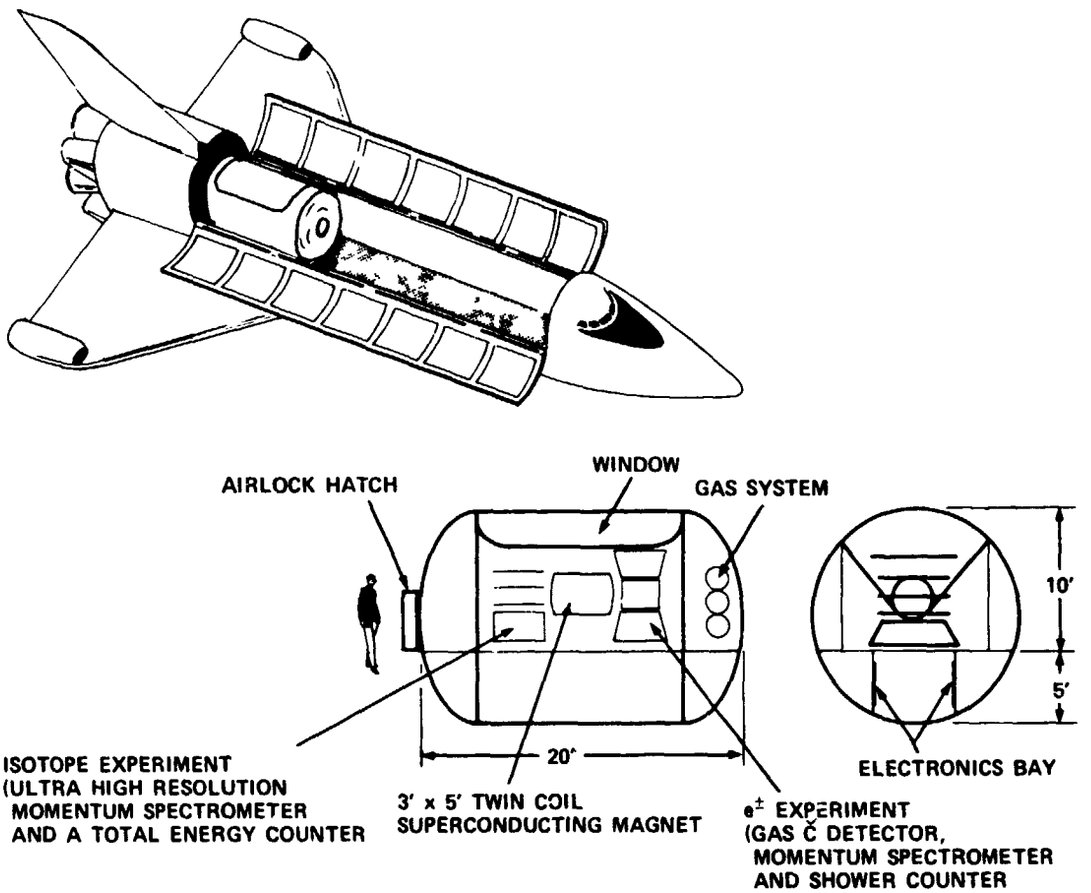


Figure 11-2. Shuttle Sortie Cosmic Ray Lab
Two Typical Experiments are Shown Installed

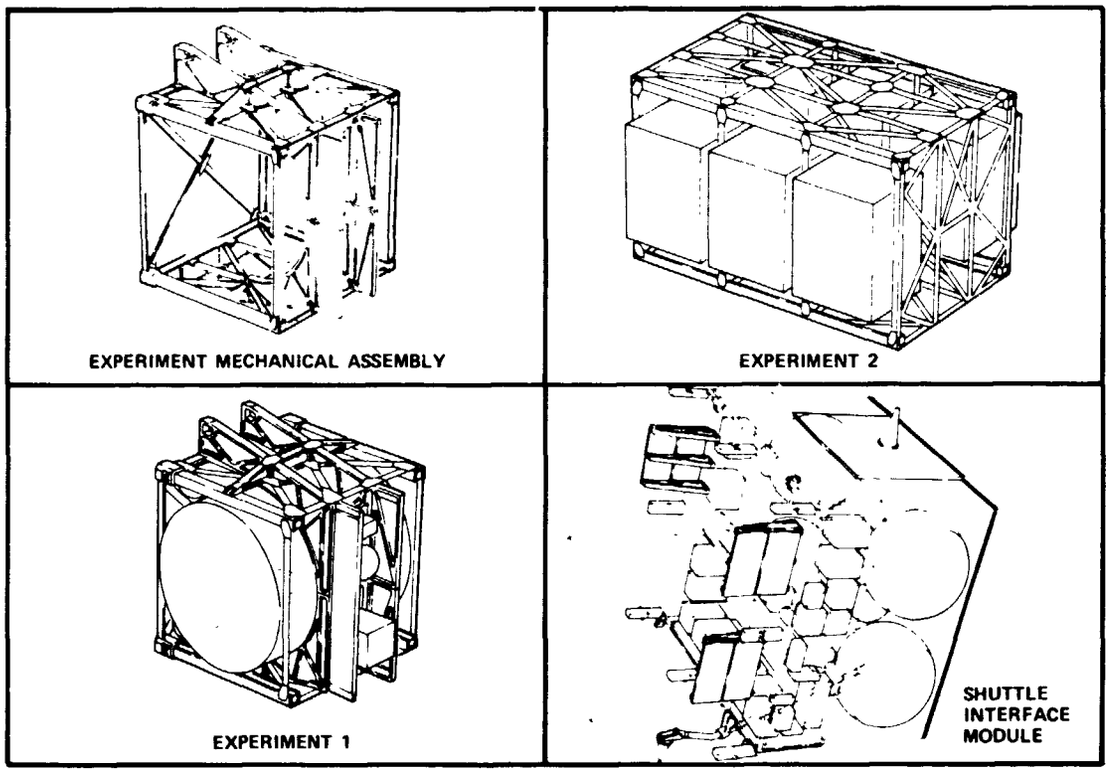


Figure 11-3

1 kw would be required so that power consumption need not be optimized. It would be most desirable if it was possible to observe the sky while other experiments are observing the ground. This could be done through an area of thin skin or a removable hatch in the lower shuttle bay or by lifting all experiments out of the bay. Typical shuttle cosmic ray packages and interface units are shown in an attached figure (Fig. 11-3) and are described in Appendix B.

EXPERIMENT MANAGEMENT

Each experiment would be conducted under the overall direction of the responsible investigator, who may either be a "Principal Investigator" as defined in NMI 7100.1 or may represent a team of cooperating scientists. This investigator may be a NASA employee or work in an academic or industrial enviroment. There would, however, be substantial differences in the way experiments were managed in the three different modes of using the shuttle capability.

- Free flying cosmic ray observatory

This is envisioned as a large facility on which a number of experiments would be flown. The payload selection would be in a manner similar to that for the HEAO's, A and B where groups of experimenters proposed jointly. They might act as user groups so that broader participation in use of the data could be envisioned. Shuttle capability would allow experiment reconfiguration by other independent proposers including scientists outside the user group. The construction and operation of the free flyer would be managed by a project group at a NASA field center.

- Cosmic ray sortie laboratory

  The sortie laboratory would be operated by a NASA center with the active participation of a user oriented steering group. Approval of experiments to be conducted in the sortie lab should not require extensive review by scientific advisory groups unless an experiment involves extensive reconfiguration of the facility. Conflict of interest would be avoided by assigning a fraction of opportunities to outside groups. In general, a user should be assigned more than one flight opportunity. Quality assurance of special hardware should be the responsibility of the investigator and he should be judged on his overall performance rather than on success or failure of a particular mission. The setting of priorities by independent groups and and the separation of the funding and selection processes were discussed as ways to control conflict of interest and ensure fairness to all experimenters.

- Sortie instrument packages

  Each experiment would be proposed by a Principal Investigator (P.I.) or a P.I. team. A NASA center would be responsible for final testing and shuttle interface. A simplified form of P.I. selection is recommended in an analogy with the present balloon and sounding rocket operation. It is proposed that a P.I. be funded at a level of effort. When his payload is ready, he brings it to the interface center where it and other experiments are assembled for inclusion in the next available shuttle flight. An experimenter would be expected to update, improve, modify and refly his equipment several times. This would have two benefits. The P.I. would not have to do everything on one flight, and he would have another chance in the event of a failure beyond his control. The program should emphasize fixed costs rather than fixed objectives. Flight opportunities should be made available to new workers in the field. The entire experiment should be the P.I.'s responsibility. NASA should supply adequate instruction books and guidelines, and then delegate all further responsibility for the hardware. This mode of operation would allow early payload involvement with the shuttle, fast experiment turn around, wide participation, and easy access to shuttle opportunites.

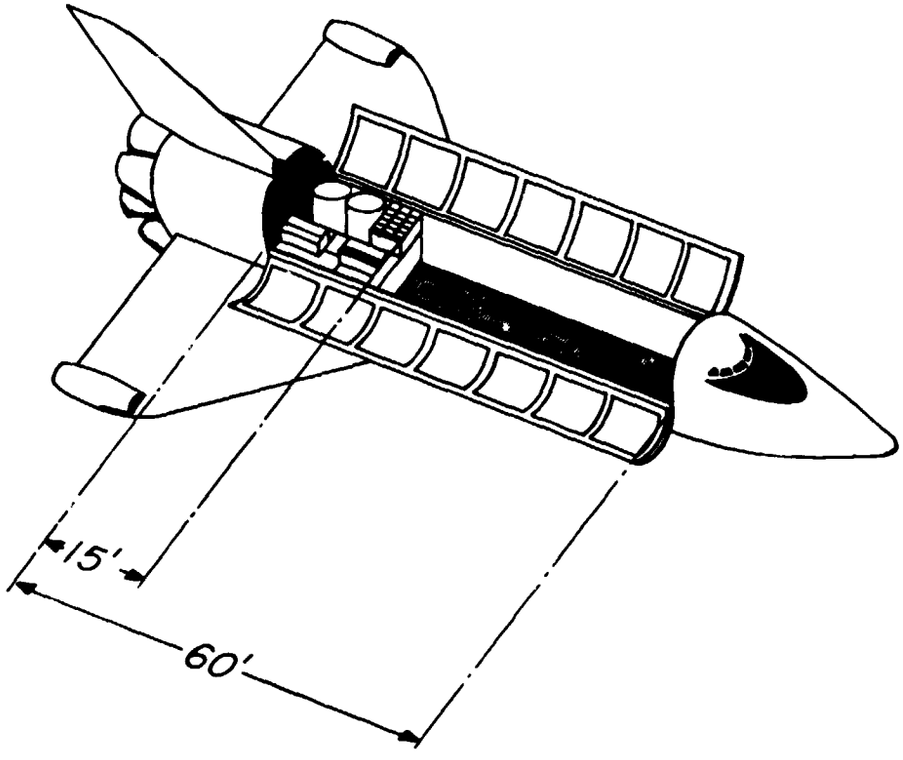


Figure 11-4. Sortie Can Exterior Layout

RECOMMENDATIONS FOR FURTHER STUDIES

This report of the working group represents only a first assessment; it should be reinforced and refined on the basis of further tradeoff and feasibility studies. In the following, the most necessary studies are listed:

- The feasibility of developing a large, modular, free flying, observatory that can be maintained in space should be explored. Such an observatory might incorporate not only cosmic rays but also X-ray, gamma-ray, and infrared experiments. Questions which must be addressed are how man interacts with the observatory, how the observatory is pointed and stabilized, how it can be easily reconfigured, and how to capitalize on developments under the HEAO program and on the shuttle instrument packages.

- An evaluation should be made of the tradeoffs between a specialized and generalized sortie laboratory for cosmic rays. The safety problems connected with man working near a superconducting magnet and near a large area thin window in the sortie laboratory must be evaluated. The questions of IVA, of man-rated equipment, and of direct versus remote operation

must be evaluated. Cost tradeoffs should be considered. The thermal problems must be examined, including the power consumption and dissipation problem. The magnetic cleanliness problem must be investigated. Various sizes and configurations for the laboratory should be considered to arrive at an optimal design.

- The panel recommends that feasibility studies be conducted of the sortie instrument package concept, both for cosmic rays and related disciplines. Particular problems of data handling, power requirements and dissipation, computer location, standardized electronics units, and the interaction with man must be examined. Emphasis should be on defining the standard module which will represent the interface to the shuttle. The possibility of developing a standard experiment housing should be studied.

- An expanded science working group should be established to define further the scientific objectives, the instrument requirements, and the capability needed on the shuttle. The ideas of non-NASA participants from the academic community and industry are needed. Close liaison should be established with the X-ray and gamma-ray working groups because of the similarity of objectives and the potential commonality of experimental subsystems. Shuttle presentations to be made to the expanded group should be brief (at most one half day) and should focus on the specific problems of interest to the working groups. General background information should be supplied to each working group member in the form of a simple report.

APPENDIX A

HIGH ENERGY COSMIC RAY SORTIE LABORATORY

APPENDIX A

DISCIPLINE AREA

High Energy Cosmic Ray Sortie Laboratory

DESCRIPTION

The laboratory is conceived of as a standardized enviroment in which experiments can be installed and performed with a minimum of time and effort. The laboratory would operate attached to the shuttle pallet for 7-30 day missions. The mode of usage would involve multiple experiments in each flight with reuse of the basic laboratory throughout the 1980's. The laboratory-shuttle interface would be essentially unchanged from mission to mission. Primary means of experiment control would be through a data link to an experiment console in the shuttle crew compartment and/or to the ground as the experiment requirements dictate. The degree of involvement of man would range from occassional experiment supervision at a remote console to IVA or EVA, depending on experiment requirements, manpower availability, ease of man rating and payload maturity. The laboratory would almost certainly be remotely operated in early flights.

The basic laboratory is shown in the Figure 11-2. The size illustrated is sufficient to contain the anticipated experiments and in most cases several experiments can be accomodated at once. It also allows operation of a 2-1/2 ft. diameter superconducting magnet while maintaining magnetic fields outside the laboratory of less than 100 gauss.

The upper portion of the lab is an experiment deck with suitable mounting structures to accomodate a wide range of experiments. A window is provided above the experiment deck which can be tailored to individual flight requirements (i.e., a thin window for flights which have a low "mass-in-beam" requirement; a thicker window if the lab is to be manned or a re-entrant window for flights that require zero overhead mass). The window would also serve as an access hatch through which large experiments would be installed on the experiment deck.

Standard electronics racks would be mounted beneath the experiment deck. This allows minimum cable lengths and optimized thermal coupling to the shuttle.

There is a very high degree of commonality in systems used by different cosmic ray experiments. The laboratory would contain a number of these standardized

subsystems for use at the discretion of the experimenter. These basic elements are:

- Power system
- Gas systems
- NIM logical electronics system
- CAMAC digital data system
- Experiment control system
- Housekeeping data system
- Shuttle master caution alert system

The power system would provide various standard voltages from remotely controllable power supplies.

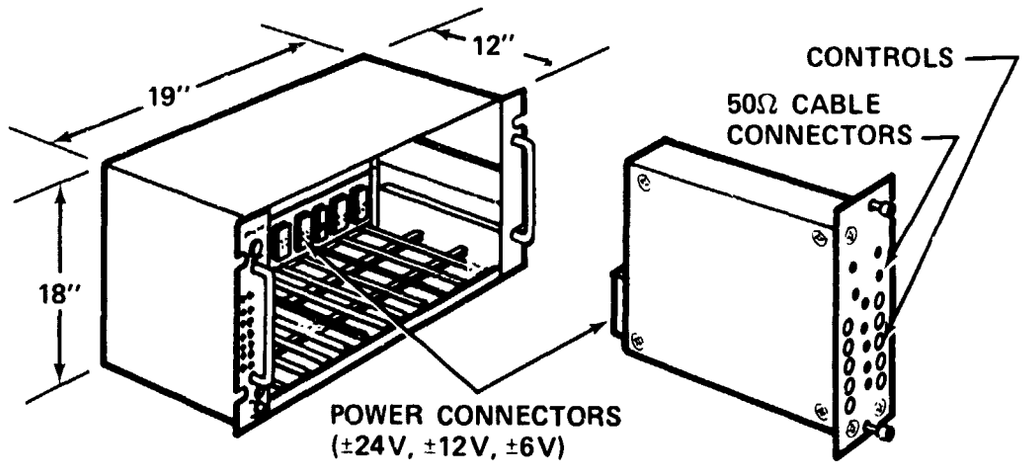
The gas systems will be available to provide spark chamber and Cerenkov detector gases and proper vents for cryogenic systems.

The NIM logic system is the same system now used universally for laboratory research. Standard 19" NIM racks are wired to provide power to commercially available, or experimenter supplied, logic modules (see Figures 11-A-1 and 11-A-2). The NIM standard also assures compatibility of logic signals, etc. Typical modules perform such functions as high speed pulse height discriminators, coincidence units, gate generators, etc. Available NIM electronics tends to be rather high on power consumption, but lower power versions can be made readily available. The NIM racks in the shuttle would provide power and thermal control to whatever set of logic elements the experimenter requires.

The CAMAC digital data system is a sister to the NIM system. Standard 19" CAMAC racks would provide power for digital data modules used by the experimenter. The racks would also provide 24 bit two-way digital data exchange with an onboard digital computer. Each module is directly addressable by the computer. Typical modules perform functions such as analog-to-digital conversion, scalers, etc. These modules can also perform command functions, such as relay closures, when instructed to do so by the controlling computer.

The experimenters would acquire their digital data by plugging appropriate modules into the CAMAC racks. A typical experiment uses high speed NIM logic to

A STANDARD NIM RACK AND MODULE



A STANDARD CAMAC RACK AND MODULE

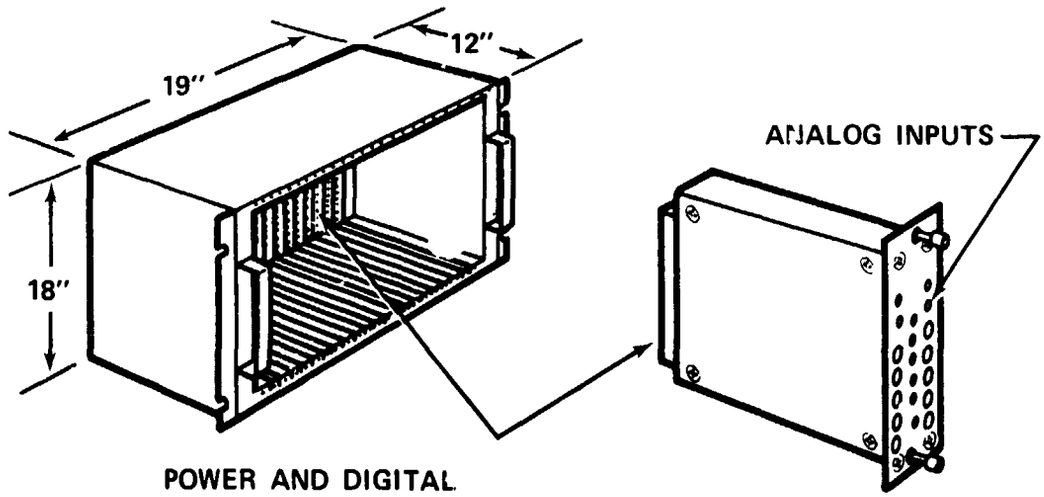


Figure 11-A-1. NIM and CAMAC Components

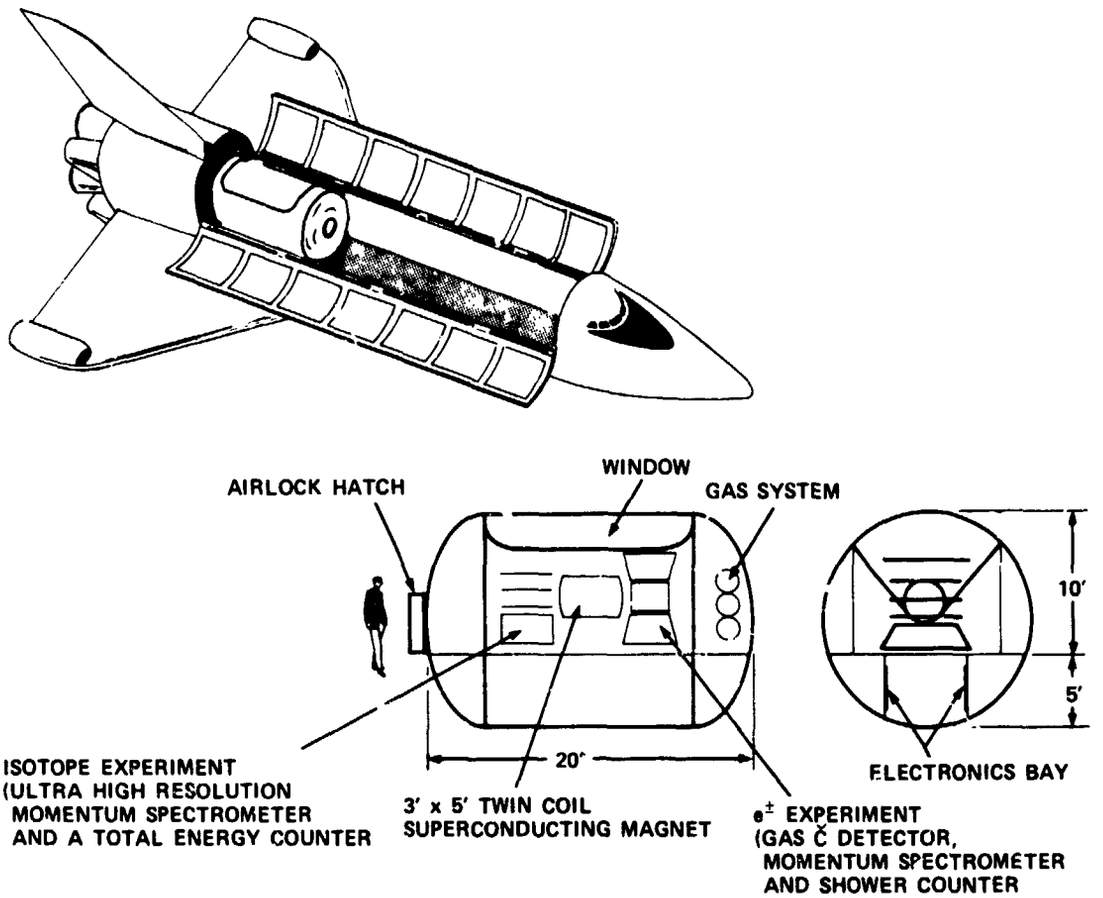


Figure 11-A-2. Shuttle Sortie Cosmic Ray Lab
Two Typical Experiments are Shown Installed

recognize an event of interest. The NIM logic then initiates digitization of the relevant data by sending a logic signal to the appropriate CAMAC modules.

Experiment control and housekeeping would also be done by use of appropriate CAMAC modules.

A small digital computer would be used to interface the experiment with the control console and data storage/transmission systems. The software would be provided primarily by the experimenter. It would be specially tailored to match the experimenter's data summary and experiment control needs. The standards mentioned above have been employed in balloon experiments with a very high degree of success. The degree of versatility in the NIM-CAMAC systems lends a definite impetus to innovative research.

A shuttle master warning and caution signal is required from all shuttle payloads that could possibly constitute a hazard. In the Shuttle-Sortie Cosmic Ray Lab provisions would be made to activitate the master caution light in case of fire, unusual gas pressures, etc.

The back end of the lab would contain a "hazardous equipment bay" in which pressurized gas systems, etc. would be installed.

Also, an airlock compatible hatch is provided both for ground access to the experiments and electronics area and for in-flight access on missions requiring manned operation.

REASONS FOR PREFERENCE OF SHUTTLE SORTIE MODE:

- Mission length and basic shuttle support capabilities allow use of lab-type rather than spacecraft-type electronics.
- Allows use of detectors that must be recovered. For example, nuclear emulsions are the best known cosmic ray spatial detector, they must be recovered for analysis. Magnet experiments done with nuclear emulsions rather than spark chambers have one hundred times greater resolution.
- High rate of flight opportunity and return of experiment allows each experiment to be more responsive to information gathered by its predecessors. Also, costs of equipment can be amortized over a large number of uses.
- Presence of man allows real-time observation and response. Traditionally, cosmic ray physics has been done without man in the loop but the new magnet spectrometers obtain data on a wide range of experiments at once. It is probable that the "observatory" mode of research will become popular in cosmic ray physics.

MISSION REQUIREMENTS

- Length of flights — 7-30 days. Several flights per year.
- Orbit — normally 28° inclination with altitude less than 250 nm. Higher inclinations, including polar orbits, will also be desired for specific flights.

- Data — 5-20 K bits/sec. continuous onboard storage or relay to ground. In the case of onboard storage -- data dumps to ground would be required several times per day. The data dumps would be perhaps 5% of the total data gathered.

- Role and Number of Personnel in Orbit — Depends strongly on experiments being performed and the availability of a data-to-ground link. Normally a payload specialist would control the experiment through an experiment control console. The laboratory data system will provide a high level of real-time onboard data summary but the specialist would also work closely with a ground team which analyzes the orbit-ground data dumps.

  Once the experiment start-up procedures are completed, the workload would normally change to occassional inquiry of experiment status, and remote adjustment of experiment controls.

  More sophisticated experiments could utilize IVA for inflight electronics reconfiguration and adjustment, detector alignment and emulsion changing tasks. EVA and/or manipulators could also be utilized to deploy possible appendages to the laboratory (e.g., a large, low pressure gas bag attached to the laboratory window).

- Stabilization and Pointing — In general, the lab vertical needs to be pointed within 45° of gravitational vertical during data-taking times. Orientation information accurate to about 0.5° will be required postflight.

  In the event that the laboratory contains x-ray or gamma-ray experiments, much higher pointing accuracy is required. It should be noted that superconducting magnets used in the laboratory would be of the twin-coil design so as not to induce torques on the spacecraft.

- Power and Thermal — The power budget depends on a number of tradeoffs. Low power requires additional complexity but it can be achieved. The laboratory could, in general, operate on 300-500 watts continuous but the availability of 1000-1500 watts continuous (for 7 days) power would greatly facilitate experimentation. Most experiments would work well in -10, +35 ° C limits.

- Weight and Volume — The empty laboratory would probably weigh ~10,000 lbs. Experiments would weigh 1-10,000 lbs. The laboratory would occupy about one third of the payload bay.

E

- Correlative Measurements — At present no special correlative measurements need be performed except those of orbit parameters and orientation.

- General Support Equipment — Specialized ground support equipment would consist mainly of gas purge and fill systems and cyrogenic supply systems. For most experiments cyrogenic systems would be filled prior to installation of the laboratory in the shuttle and would not require any further resupply. An equipment pool staffed by 1-2 resident instrumentation experts would be required. These personnel also would assist the experimenters in payload integration.

- Documentation Requirements — NASA would be required to provide an up-to-date user's manual. The experimenter and the mission payload center would be required to provide an experiment description and procedures handbook including a list of engineering specifications, a description of the electrical systems, and a safety test plan.

- Special Operating Constraints — None.

- Contamination requirements — no large nearby radioactive sources.

POLICIES AND PROCEDURES CONFLICTS

If the laboratory is to gain wide acceptance and use, basic responsibility for reliability must be shifted to the experimenter; safety supervision should be placed in the hands of the NASA engineers and technicians who assist in the payload integration and checkout.

THE USER COMMUNITY

The user community is essentially the entire cosmic ray community. A total of 92 institutions were represented at the last International Cosmic Ray Conference. At least 30 of these institutions are capable of providing their own hardware to put in the laboratory.

INTERFACING WITH THE USER COMMUNITY

Interaction with the user community should be integrated into the program through formation of an informal panel. This panel would generate inputs to help guide the laboratory development. In turn, the panel members would learn

the laboratory's capabilities and limitations, and start steering their research programs toward shuttle experimentation.

A laboratory user's guide would be generated as the laboratory design evolves. This user's guide would be distributed to all potential experimenters. It would provide the basic information required to plan an experiment.

Implementation of an experiment would follow a chain of events in many ways similar to an accelerator or balloon experiment. Once an experiment was conceived it would be described in a proposal using the laboratory users guide as an aid in establishing the best configuration for the experiment. Upon approval of the proposal, the experimenter would construct the experiment using his own or commercial NIM and CAMAC electronics. The experiment would be checked out in the experimenter's laboratory and an appropriate set of procedures and control software devised. The experiment would then be shipped to KSC and be integrated into the shuttle laboratory with the assistance of resident payload technicians and engineers. During the integration and checkout, the experimenter would gain first-hand experience with the shuttle operations. He would then be able to further improve his procedures and experiment control software. The experiment would then be flown and returned.

RECOMMENDED PLAN OF ACTION

Pre-Phase A planning is being initiated at MSC. The objectives are:

- To further identify user requirements through informal inquiry to both in-house and outside users.

- To generate a conceptual design including cost estimates, instrumentation description and a recommended mechanism for implementation of the design. A thorough review of the RAM, Soar and Sortie lab designs will be an integral part of the effort. The work will also include an exploration of the various modes of man involvement and an assessment of their practicality particularly with regard to the related safety qualification procedures.

The time scale for this effort will be 6-12 months. It will be an integrated part of further efforts of the working group.

APPENDIX B

SHUTTLE SORTIE INSTRUMENT PACKAGE

APPENDIX B

DISCIPLINE AREA — SHUTTLE SORTIE INSTRUMENT PACKAGE

The shuttle sortie utilization described below is keyed to the needs of cosmic ray physics but should also be applicable to related disciplines of solar physics, X-ray, gamma-ray, and IR astronomy.

DESCRIPTION

- Configuration — An instrument package is proposed as a relatively simple, flexible and cost-effective means of conducting scientifically significant experiments on the shuttle sortie vehicle. This package requires only a fraction of the shuttle capability and could be flown on a space available basis. Many of the characteristics are patterned after the manner in which balloon flight and sounding rocket experiments are performed. Key aspects of this approach are to minimize direct interfaces with the shuttle, where possible, to use standard and common electronic and mechanical subsystems, to minimize the time from conception to execution of an experiment and to take advantage of a basic characteristic of the shuttle to allow for repeat flights of the same instrument.

  The instrument package would consist of from one to six individual experiments placed on a pallet which could be located aft of the pressurized module for the sortie lab concept shown in Fig. 11-4. The pallet would be designed so that the volume used would be proportional to the size of any particular package. The instruments themselves would be built around the pallet in modular fashion as illustrated in Fig. 11-3. This separability allows any combination of instruments to be flown. A pressurized enviroment is recommended for the experiments in order to simplify design and operation by not requiring function through the corona range of low pressure or testing in a vacuum.

- Common systems — The high degree of commonality among different cosmic ray experiments will allow a number of standard systems to be installed in a service or shuttle interface module for use at the discretion of the experimenter. These would include:

  - a power system to provide a minimum number of standard voltages from the shuttle power supply and, an auxiliary power supply, if necessary.

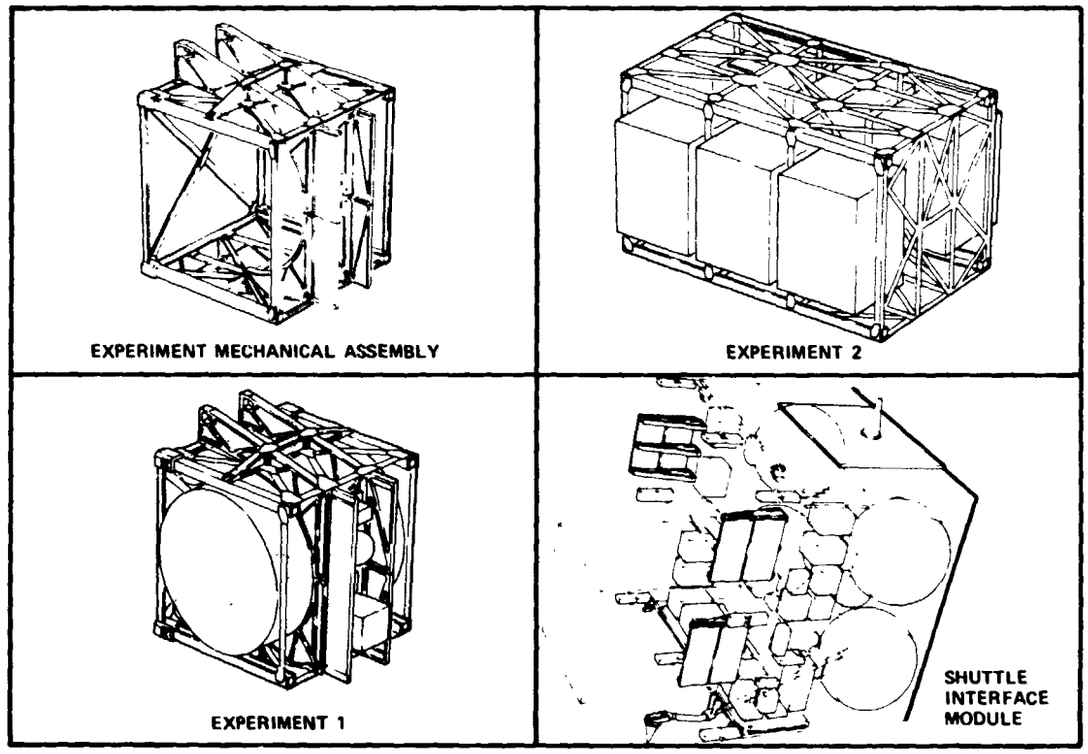


Figure 11-3

- gas systems to provide spark chamber, Cerenkov detector and proportional counter gases and venting for cyrogenic systems.

- A digital computer for data processing and control. This would be used to interface each experiment with the data storage and transmission systems as well as with the shuttle control console if an experimenter wished to make use of an on-board mission specialist for command control or monitoring. The software would be tailored to match the experimenter's data summary and experiment control needs.

- a data storage system, either as a separate unit or part of the data processing and control system.

- a housekeeping data system.

- Standardized subsystems — Standardized subsystems for use in individual experiments and in the interface module offer major advantages in terms

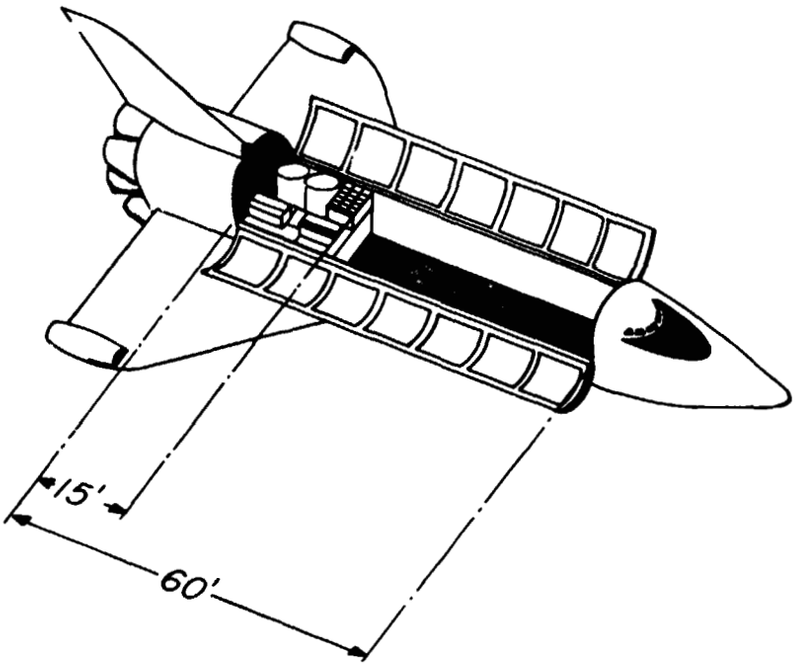


Figure 11-B-4. Sortie Can Exterior Layout

of availability, interchangeability and cost savings. Areas identified to date are:

- NIM logic electronics
- CAMAC digital data system
- pressure valves and regulators

The NIM logic system is the same system now used universally for laboratory research and is beginning to be used in balloon flight experiments. Standard 19" NIM racks are wired to provide power to commercially available, or experimenter supplied, logic modules. The NIM standard also assures compatibility of logic signals, etc. Typical modules contain circuits like high speed pulse height discriminators, coincidence units, gate generators, etc. Available NIM electronics tends to be rather high on power consumption, but lower power versions can be made readily available. The NIM racks in the shuttle would provide power and thermal control to whatever set of logic elements the experimenter requires.

The CAMAC digital data system is a sister to the NIM system. Standard 19" CAMAC racks would provide power for digital data modules used by the experimenter. The racks would also provide 24 bit two-way digital data exchange

with an on-board digital computer. Each module is directly addressable by the computer. Typical modules perform functions such as analog-to-digital conversion, scalers, etc. These modules can also perform command functions, such as relay closures, when instructed to do so by the controlling computer.

The experimenters would acquire their digital data by plugging appropriate modules into the CAMAC racks. A typical experiment uses high speed NIM logic to recognize an event of interest. The NIM logic then initiates digitization of the relevant data by sending a logic signal to the appropriate CAMAC modules.

Experiment control and housekeeping would also be done by use of appropriate CAMAC modules.

- Discussion — The Shuttle Sortie Instrument Package will be utilized by experimenters desiring relatively short periods of operation such as emulsion studies, or successive operation in different configurations, by experiments which are either preparatory for, or complementary to, long-lifetime experiments in the free-flying module.

Cosmic ray and solar particle physics has a long and successful history with experiments in space. Contemporary instrument designs can readily be adapted to the specifications of the instrument package and can be available for the initial science-oriented shuttle sortie flights. Integration of the package in the shuttle will be greatly simplified by minimizing the package-shuttle interfaces, most particularly in regard to in-flight operations. Unlike the cosmic ray sortie laboratory, the instrument package will not require the support of a payload specialist; a mission specialist would be able to perform the necessary console operations.

ADVANTAGES OF THE SORTIE MODE OVER OTHER METHODS

A simple instrument package for shuttle sortie missions offers the following advantages:

- In comparison with satellite payloads
  a. relatively short time period from proposal acceptance to execution.
  b. simplified design, construction and test program.
  c. reflyable after modification.
  d. reflyable after repair.

e. substantially lower cost per experiment.

f. more opportunity for user participation.

g. greater payload capability than on any but the most sophisticated satellites.

- In comparison with balloon flights

  a. experiments performed entirely above the atmosphere.

  b. longer operating periods (balloon flights rarely last more than a fraction of a day at float altitude).

REQUIREMENTS FOR THIS TYPE OF MISSION

- Length of flights — 7-30 days, with a preference for the longer missions in most cases.

- Orbit — Mission with both low (about 28° lat.) and high ($\geq$50° lat.) inclination are desired, about evenly divided in number. The altitude to be less than 250 nm.

- Data requirements — Up to 25 kilobits/sec continuous on-board storage or relay to ground. It will be desirable for at least 5% of the data to be dumped after each orbit.

- Role and number of personnel in orbit — A small part of one mission specialist to serve as a command relay link and console operator.

- Stabilization and pointing — The instrument package vertical will need to be pointed within 45° of the gravitational vertical (upward) during period of data-taking. Orientation information accurate to 0.5° will be required postflight.

- Power and thermal — Power requirements will vary according to the experiment complement of the package but, based on recent HEAO experience, and reasonable projections to lower cost standardized electronics, 1000 watts of continuous power will be needed. (Note: According to pp. 3-20 of MSC's Shuttle Workshop presentation material, 50 kwhr is nominally available. For the 7-day shortest shuttle sortie mission, this allows only 300 w of continuous power for the entire payload - a serious deficiency).

An operating thermal range of -10° to +30° C is desirable though wider limits can be accommodated.

- Weight and volume — Weight up to 10,000 Kg, though in most cases it should not exceed 5,000 Kg.

  Volume — 300 ft^3 maximum.

- EVA requirements — None.

- Correlative measurements — Orbit parameters and shuttle orientation.

- General support equipment

  a. As noted under Common Systems.

  b. Ground support-equipment for assembling and loading the instrument package, gas purge and fill systems and cryogenic supply systems.

- Documentation requirements — In order to minimize documentation requirements, NASA should provide a comprehensive users' manual; the experimenter should provide:

  a. an end item specification.

  b. interface characteristics.

  c. a safety assessment.

  d. mission operations requirements.

- Special operating constraints — Operation as noted under Stabilization and Pointing at least 50% of the time.

- Contamination requirements — None required!

- Other — Frequent flight opportunities are desired, i.e., monthly. It would be most desirable if a thin section or hatch in the lower shuttle bay would permit entry of cosmic rays from that direction.

POLICIES AND PROCEDURES REQUIRED TO EXPLOIT THE SHUTTLE SORTIE MODE AND REDUCE COSTS

The high costs of space experimentation to date are the result of:

- Limited weight and volume
- Limited power
- High level of R and QA and of safety assessment
- High level of documentation and review
- Length of time required for design, fabrication, test and integration cycle.

Potential cost drivers which can be identified for the shuttle sortie instrument package are:

- Safety considerations required to produce a man-rated enviroment around the instrument package.
- The impact on training and the time line if extensive use is made of the payload and mission specialists.

The policies and procedures required to exploit the shuttle sortie mode and reduce costs of the proposed instrument package are:

- Shift responsibility for R and QA to the experimenter.
- Standardize on NIM logic electronics and a digital data-command system such as CAMAC.
- Standardize on multi-use interface systems such as gas systems, mechanical mounting, power conditioning.
- Establish a simple interface with the shuttle, and minimize need for safety precautions by not requiring manned access to the instrument package.
- Certify for safety on the basis of:
  a. Project review of specific potentially hazardous subsystems only and on the subsystems rather than the component level.
  b. Pre-flight testing like vibration and acceleration loading.

- Provide adequate power, weight and volume to avoid the need for highly sophisticated and expensive low power circuitry and compact packaging.

- Eliminate most of the documentation requirements and minimize frequency and extent of remaining documents.

- Confine the pre-flight test program essentially to:

  a. Functional testing

  b. Electrical and thermal stress

  c. Vibration

- Eliminate parts screening except in special situations, e.g., a photomultiplier tube where resolution, response or stability may be critical.

- Assign each user more than one flight opportunity if needed to overcome initial problems or alter the scope of an experiment based on an analysis of the data.

- Eliminate custom-tailored ground support units for individual experiments.

ESTIMATE OF USER COMMUNITY

A total of 92 institutions were represented at the last International Cosmic Ray Conference. At least thirty of these are capable of providing experiments for the instrument package. Other disciplines, notably solar physics, X-ray astronomy and gamma-ray astronomy, are expected to find the instrument package attractive.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

A rotating panel of potential and current users of the instrument package appointed by NASA should be involved in scheduling approved experiments for the package, advising NASA on repeat flights, and initiating or reviewing suggestions for modifying instrument package interfaces.

Access to the instrument package would be via formal proposal to NASA. Upon approval, the investigator(s) would be responsible for construction of the experiment using a comprehensive users' guide and advice from the responsible

Project Center. The latter would conduct a design review confined to the ar[illegible] of safety, interfacing, and external configuration. Functional performance would be established in the experimenter laboratory and an appropriate set of procedures and control software devised. After post-vibration functional tests, the experiment would be shifted to KSC for integration in the shuttle laboratory.

RECOMMENDATIONS ON FUTURE ACTIONS TO IMPLEMENT THE SORTIE MISSION

- Undertake a more detailed definition study into the feasibility of the Shuttle Sortie Cosmic Ray Instrument Package concept, identify problems, solutions, instrument characteristics, required shuttle capabilities and safety concerns (JPL has already proposed and GSFC has expressed interest in such a study). Interface discussions with MSFC and MSC will be included.

- Expand the present science working group with members of the academic community in order to further define scientific objectives, review the results of the detailed definition study, and prepare a position report.

- Schedule an interdisciplinary meeting among those science working groups with a potential interest in the instrument package, i.e., cosmic ray, solar physics, X- and gamma-ray astronomy, IR astronomy and possibly others.

- Following the completion of definition studies, NASA should appoint the user panel and assign project management responsibility to a Center(s) for the instrument package.

- In addition to implementing a design for the instrument package, the pallet, and the development of the common service systems; support is also required for investigators to develop advance detector systems and test the workability of newly proposed procedures.

X-RAY AND GAMMA RAY ASTRONOMY WORKING GROUP

CONTENTS

	Page
INTRODUCTION	12-1
POTENTIAL CONTRIBUTIONS OF SORTIE OPERATIONS	12-4
APPENDIX A LABORATORY AND PALLET ENVIRONMENT	12-A-1
APPENDIX B X-RAY AND GAMMA RAY ASTRONOMY	12-B-1
APPENDIX C X-RAY AND GAMMA RAY ASTRONOMY	12-C-1
APPENDIX D X-RAY AND GAMMA RAY ASTRONOMY	12-D-1
APPENDIX E MINUTES OF FIRST X-RAY ASTRONOMY GROUP	12-E-1
APPENDIX F WORKING GROUP REPORT FORMAT	12-F-1

X-RAY AND GAMMA RAY ASTRONOMY WORKING GROUP

INTRODUCTION

High energy astronomy is very young compared to optical astronomy. It is, however, already known to be an extraordinarily rich branch of astronomy and to hold great rewards for those pursuing knowledge of the major energy transfer mechanisms in the universe. Studies of the goals and objectives in X-Ray and Gamma Ray Astronomy have been conducted by the National Academy of Sciences and the NASA Astronomy Missions Board*. We endorse these goals and objectives, and we have repeated, or expanded on, these studies only to the degree necessary to establish a framework for the discussion of the use of the space shuttle in X-Ray and Gamma Ray Astronomy.

The discovery and study of objects which have almost all of their energy output in the X-ray range have already made substantial contributions to our understanding of high energy processes. Temporal variations, in particular, have been a rich source of the identification of the energy sources required to drive the high energy processes involved in X and gamma ray production.

Gaps still remain in our understanding of crucial aspects in the evolution of high-energy photon emitters. The evolution of supernova remnants, the details of the output mechanisms of X and gamma ray sources, and the energy input parameters are problems we would hope to tackle in the next generation of experiments. There is, in addition, the need for detailed study of the diffuse radiation, both galactic and intergalactic, to determine the distribution, dynamics and history of the nuclear and electron components of cosmic rays, as well as other phenomenology related to the diffuse X and gamma radiation.

In describing the goals in this field for the 1980's, X and Gamma Ray Astronomy will be divided into four energy intervals. The divisions by energy are based

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*Priorities for Space Research, 1971-1980, National Academy of Sciences, Washington, D.C., 1971.

Astronomy and Astrophysics for the 1970's. Volume 1 Report of the Astronomy Survey Committee, National Academy of Sciences, Washington, D.C., 1972.

A Long Range Program in Space Astronomy; Position Paper of the Astronomy Missions Board, Edited by Robert O. Doyle, NASA SP-213, 1969.

upon the physical processes responsible for radiation at these wavelengths and on the instrumentation required to study the radiation. The boundaries between the intervals are, therefore, not sharply defined in physical terms.

A. X-RAY ASTRONOMY (0.02-2 KeV)

Research objectives:

I. Detailed study of the energy emission spectra, particularly line emission from light elements.

II. Investigation of the interstellar and intergalactic media through the use of absorption features in the spectra.

III. Temporal studies on time scales greater than one millisecond, both periodic and aperiodic.

IV. Polarization studies, particularly of extended objects, as a tool in identifying emission mechanisms.

V. Survey for weaker sources not yet detected.

VI. Study of spatial variations over extended objects and precise location of point sources.

VII. Correlation with radio, optical, and higher energy emission.

B. X-RAY ASTRONOMY (2-50 KeV)

Research objectives:

I. Detailed study of spectral features with resolution sufficient to resolve heavy element K emission (e.g. Fe) and sharp continuum features which can be signatures of emission processes.

II. Temporal analyses on time scales from less than a millisecond to a year in order to identify energy input processes.

III. Spectral correlation with lower energy X-ray absorption measurements to identify cosmic ray induced emission (both continuum and line) in the interstellar medium.

IV. Polarization studies.

V. Correlation of temporal variations with measurements in other regions of the electromagnetic spectrum.

C. LOW ENERGY GAMMA RAY ASTRONOMY (0.05 to 10 MeV)

Research objectives:

I. A study of specific sources of gamma ray line emissions which may have been discovered in the sky survey performed by HEAO. Some expected source mechanisms are:

   a. Line emissions from nucleosynthesis in stellar objects.

   b. Line emissions from excited nuclei in energetic regions.

   c. X-rays from atomic transitions in very heavy elements.

   d. 511 KeV line emission from electron-positron annihilation.

II. Determination of the location, extent, intensity, degree of polarization, and detailed spectrum of X-ray and gamma ray sources in the 0.05 to 10 MeV energy interval.

III. A search for new X-ray and gamma ray sources in the 0.05 to 10 MeV energy interval.

IV. Observation of the time variations in the intensity and spectral details of discrete X-ray and gamma ray sources.

V. A study of the origin, isotropy and spectral details of the diffuse X-ray and gamma ray background.

VI. Correlation of temporal variations with measurements in other regions of the electromagnetic spectrum.

D. HIGH ENERGY GAMMA RAY ASTRONOMY (>10 MeV)

Research objectives:

I. A full sky survey at high sensitivity for discrete sources and measurements of their flux, energy spectrum, and location.

II. A detailed study of specific gamma ray sources with fine time, energy, and spatial resolution to determine their physical characteristics.

III. Study of the galactic plane structure with high sensitivity, good energy resolution, and fine angular resolution to understand in depth the distribution of cosmic rays and their role in the dynamics of the galaxy.

IV. Measurement of the intensity and energy spectrum of the diffuse radiation from regions other than the galactic plane.

V. Search for short intense bursts of gamma rays, such as those expected from supernova explosions.

VI. Correlation of gamma radiation emitted by sources with X-ray, optical, and radio emission from the same source.

POTENTIAL CONTRIBUTIONS OF SORTIE OPERATIONS

Identifications of the potential contributions the sortie mode can make to specific discipline goals and objectives follow; considered are three types of missions which have been designated:

(a) Basic sortie, characterized by a pointing capability of ~1° and a stabilization of ~0.1°/sec.

(b) Pointed sortie, characterized by a pointing capability of ~0.1° and a stabilization of ~0.01°/sec.

(c) Sortie deployed satellite, characterized by a stable inertial reference frame (same pointing and stability as (b)) on a satellite which can remain in orbit for up to six months.

The general philosophy adopted in considering specific sortie missions for each of the scientific objectives is the effective utilization of each of the three conceived mission types. The basic sortie missions will have instruments which can effectively utilize the limited exposure without the necessity of improved pointing (e.g., instruments collimated to a few degrees). The pointed sortie will allow the inclusion of instruments which require precise pointing (e.g., grazing incidence telescopes and dispersive instrumentation). The third mode will include those objectives for which long exposure times must be obtained (e.g. survey missions for gamma ray sources).

The following table indicates which of the objectives in the previous section can be studied in the different mission modes. In other words items appearing

in the third category could not be accomplished in the first or second, but items appearing in the first or second could be accomplished in the third.

BASIC	POINTED	EJECTED SATELLITE
AII	AI	AV
AIII		
AVII	AIV	CIII
BI	AVI	CV
BII	BIV	DI
BIII		DIV
BV		
CI		
CII		
CIV		
DII		
DIII		
DV		
DVI		

DESCRIPTIVE TITLE OF SORTIE MISSIONS REQUIRED FOR EACH OF THE POTENTIAL CONTRIBUTIONS LISTED ABOVE

a. Basic Shuttle sortie Coarse Pointed Mission (Pointing to 1°. Jitter rate $< 0.1°$/sec).

b. High Accuracy Pointed Mission (Pointing to 0.1°. Jitter rate 0.01°/sec).

c. Shuttle-Deployed Satellite Missions

DESCRIPTIVE TITLES OF SORTIE MISSIONS FOR WHICH REQUIREMENTS AND CHARACTERISTICS ARE OUTLINED IN ATTACHED APPENDICES

Same as above.

OUTLINE OF THE PROPOSED FLIGHT SCHEDULE OR SORTIE AND NON-SORTIE MISSIONS NEEDED TO MEET THE DISCIPLINE GOALS AND OBJECTIVES

YEAR	BASIC SORTIE MISSION	POINTED SORTIE MISSION	SORTIE DEPLOYED SATELLITES
1979	4		HEAO-C (X)
1980	4		

YEAR	BASIC SORTIE MISSION	POINTED SORTIE MISSION	SORTIE DEPLOYED SATELLITES
1981	2	1	HEAO-D (Gamma)
1982	1	2	Deployed Spacecraft
1983	1	2	Refurbished HEAO-C
1984	1	2	Deployed Spacecraft
1985	1	2	Reconfigured HEAO-D
1986		3	Deployed Spacecraft
1987		3	Reconfigured HEAO
1988		3	Deployed Spacecraft
1989		3	Large X-Ray Telescope
1990		3	Deployed Spacecraft

POLICIES AND PROCEDURES WHICH MUST BE CHANGED OR INSTITUTED TO FULLY EXPLOIT THE SHUTTLE SORTIE MODE AND REDUCE THE COST OF RESEARCH IN SPACE.

High costs in space flight operation are frequently incurred by requiring a number of experiments to be at a specific integration point simultaneously. On experiment experiencing development difficulty may require extensive funding to avoid delaying other elements of the program. If the program is delayed, costs are still higher. By permitting experiments to proceed on a development schedule not tied to a specific launch schedule, problems can be resolved without the expenditure of premium effort. Provisions should be made within the Space Shuttle program to adjust experiment flight scheduling and to relax interface and reporting controls.

This implies that the burden of delivering a functional instrument falls on the principal investigator. The shuttle program must provide an interface document to which, the experimenter will build his instrument. The working group favors an interface philosophy comparable to the CV 990 and Explorer Program interface requirements. When the instrument is delivered, the shuttle integrator spot checks interface requirements, performs a functional test, gives the instrument simple electrical and thermal stress tests, and vibrates the instrument to flight level standards. If the instrument passes these tests, it is integrated into the shuttle. If it fails, it is returned to the PI's laboratory for correction.

The techniques of implementing X-ray and gamma ray experiments on the shuttle can also have a major effect on research costs. Implementation of X-ray and gamma ray experiments seems to be best done by placing the sensor and its immediate supporting electronics — preamplifiers and high voltage power supplies — on the pallet. This instrumentation is in free space and would be built to the

reliability and test specifications generally now associated with space flight hardware on an IMP, Pioneer, or HEAO.

Other equipment associated with the experiments could be mounted within the sortie laboratory. Included would be the power supplies, shaping amplifiers, threshold circuitry, coincidence/anticoincidence conditions, counter registers, priority systems, small dedicated computers, and test systems. A major savings on the flight instrumentation can be made in this sortie laboratory equipment if the following considerations are implemented:

(a) the laboratory environment must be benign.

(b) the equipment must be reasonably modular so that building blocks may be common to many different experiments.

(c) it is highly desirable that these flight modules be similar if not identical to ground laboratory hardware.

(d) components in these modules would essentially be commercial grade parts functionally tested before usage. The test sequence discussed above would constitute the entire acceptance testing of the instrument.

The following sections deal with the rationale supporting the above:

A. While the Sortie laboratory environment is good in many respects, it is particularly bad with respect to the maximum acoustic vibration exposure. An appendix to this group report discusses the setting of a reasonable limit for the sound pressure level at 120 decibels vs. the 145 decibels presently indicated. This limit allows use of most laboratory components, instruments, and techniques. It should result in only a minimum type of vibration test.

B. A considerable cost savings will result if the laboratory equipment is building block in nature. Many experiments would use differing sets of these building blocks in assembling their systems. Smaller numbers of designs and larger volumes of a given type will reduce costs. Additionally, replacement, redesign and/or reconfiguration of the systems are greatly simplified.

C. A very complete family of linear and digital modules exists in a standard modular package called the Standard Nuclear Instrument Modules. Virtually all nuclear laboratory equipment is now built to this NIM specification. In recent years much reactor control and monitoring equipment,

medical equipment, and general laboratory equipment has been packaged and electrically specified in this way. Much of the experiment ground support equipment at the Goddard Space Flight Center has been built with this system. Balloon flight equipment from MSFC, MSC and GSFC have also used NIM modules.

In addition to the advantages already discussed for modular building blocks, the NIM system is a particularly good mechanical, electrical and thermal system. It is the best generally available for analog systems and digital circuitry other than that associated with computer interface and control. Most of the modules required for many physics and astronomy experiments exist now. Immediately and inexpensively, an experiment's electronics system could be built up, tested, and optimized. One could perhaps specify the NIM shuttle modules with the basic NIM specifications plus minimum parts, parts mounting and layout specifications.

The analog to NIM in digital data handling systems optimized for use with on-line digital processors and computers is CAMAC. This system originated with the ESONE Committee in Europe. It is now in wide-spread use throughout the world, and preparations for its implementation as a U.S. and international standard are underway. It is ideal for interfacing large experimental systems to computers.

Copies of the complete NIM specification including drawings are available through

L. Costrell, Chairman
AEC Committee on Nuclear Instrument Modules
Radiation Physics Building
National Bureau of Standards
Washington, D.C. 20234

Preprints of the CAMAC specifications, standards, and description will also be available in quantity in August, 1972, from Mr. Costrell.

NOTE: The NIM and CAMAC systems do not require equipment to operate from a 120 volt AC source. Certain DC voltages may be bused through each module bin. We would propose to even bus the shuttle 30-volt line to each bin, and modular power supplies be put in each bin to supply the required voltages/power for that/those bins. In addition to the modular simplifications, one has an additional crew safety factor.

D. For some years, balloon and sounding rocket instrumentation and spacecraft ground support equipment at the Goddard Space Flight Center have been made with commercial grade electronic parts at a great cost savings and with a very good success record. Particularly large savings have been made with respect to integrated circuits and other semiconductors. TTL logic elements of the Texas Instruments 54L family cost about $45.00 when bought to a MSFC 85MO specification for high-reliability space flight use. If bought to a commercial specification, the cost is about $5.00 - 10.00 in a hermetic flat-pack. Our balloon, rocket and GSE experience has been with plastic encapsulated circuits in the dual-inline package for $1.00 - 2.00 per package. We propose that plastic encapsulated integrated circuits, transistors, and diodes are completely adequate for use in the shuttle sortie laboratory. This will have a major impact on cost, schedule and development time. Beyond the parts themselves, one must consider the methods of parts attachment. Within the environment anticipated here, even a plug-in socket with hold-down clip will be adequate.

The above considerations of components and construction lead one directly to the use of certain commercial electronics equipment with little modification. A good example is the small purpose computer of the PDP 11 or Varian 620 nature. Reduction of GSE cost by a factor of 2-3 has been realized by using these small re-usable computers as simple, single-design, dedicated equipment. Use of these computers within the sortie laboratory (probably dedicated to each experiment) can lead to cost reduction of the on-board data processing equipment and a substantial reduction in the data bit-rate to the ground in many situations. This can be accomplished by processing, selecting and reducing the data within the experiment.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF THE SORTIE MISSION USER COMMUNITY

The working group identified approximately fifty research groups active in X-ray and gamma ray astronomy. These research groups are located at 32 domestic and foreign institutions, distributed as follows: 7 Government Laboratories, 12 Universities, 6 Industrial Organizations, and 7 Foreign Countries.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

1. Through Headquarters-sponsored discipline working groups.

2. Support of selected potential principal investigators for the design and development of shuttle flight instrumentation.

3. Integration of the outside scientific community into study groups established to investigate the concepts of shuttle scientific facilities. The feasibility study groups would be sponsored by the responsible Headquarters program offices and directed by an appropriate NASA center.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES

The working group recommends that the group be enlarged on a timely basis to include the outside scientific community. The enlarged working group should meet regularly to plan shuttle utilization in X-ray and gamma ray astronomy. Administratively responsible shuttle personnel should attend working group meetings, both from the point of view of answering specific technical/policy questions on the shuttle and assuring that working group recommendations are incorporated into shuttle design and planning on a timely basis.

In order for experiments to be ready for the shuttle when it comes into existence, SR and T effort should be initiated in FY 73 to investigate appropriate experiment configurations and particularly certain key subsystems of the experiments. Experience has shown that the accommodation of instrumentation to new packaging and operation philosophies creates new and varied problems which require immediate attention if they are to be resolved prior to shuttle availability.

Studies are also required to determine the support systems needed for the baseline sortie mission. Special attention should be directed toward determining if it is possible to develop standard systems capable of supporting many experiments. Studies are also required to investigate incorporating X-ray and gamma ray instruments into interdisciplinary facilities and means of modularizing and integrating subsystems of X-ray, gamma ray, and cosmic ray experiments into a laboratory and pallet. Investigation of both electrical and mechanical interfaces is required.

SR and T and mission definition support should be provided to begin the feasibility study of operating fine-pointed X-ray instruments from the pallet. The investigation would include techniques of operating in the presence of man, techniques of remote operation of a telescope, both from within the laboratory and from the ground via a communications link, and techniques for manipulating sensors and detectors into and out of the focus of a telescope.

Studies are required to assess the spacecraft systems required to support satellite deployment and recovery by the shuttle. Specifically, investigations are required to assure than an orbiting spacecraft can be recovered and to assure that the free-flying spacecraft are amenable to refurbishment and reconfiguration.

APPENDIX A

LABORATORY AND PALLET ENVIRONMENT

APPENDIX A

LABORATORY AND PALLET ENVIRONMENT

1. The temperatures, pressure, atmosphere, cleanliness and volume proposed for the laboratory seem to be adequate.

2. It is not at all clear that 1 to 3 KW will be adequate sortie laboratory power, however. At this time it would seem wise to carry the option of a fuel cell in the lab in addition to the three fuel cells in shuttle proper.

3. The launch-sound pressure level forecast of less than 145 decibels is a great concern. This would be a major cost driver for the scientific instruments both on the pallet and in the laboratory. A reasonable maximum acoustic environment is 120 decibels. It is believed that the need and consequences of such an attenuation are enough to justify the use of perhaps 10% of the net payload weight in structure, damping and insulation, if necessary. For further information refer to "Sonic and Vibration Environments for Ground Facilities - A Design Manual" by Wyle Laboratories Research Staff, Report Number WR68-2, Huntsville Facility, Huntsville, Alabama, submitted under NASA Contract NAS 8-11217 to MSFC. Refer to Table 11.2, Table 11.4 and Chart 12.3.

4. Internal payload bay wall temperature limits range from -73C to +93C. Most sensor systems mounted upon the pallet will have to have internal temperatures within a -40C to +40C limiting range. With the large areas of these detectors and low internal power dissipation, it is apparent that provision must be made for extensive heating, cooling, insulation, thermal shutters, etc.

APPENDIX B

X-RAY AND GAMMA RAY ASTRONOMY

APPENDIX B

A. X-RAY AND GAMMA RAY ASTRONOMY

B. BASIC SORTIE MISSION CHARACTERISTICS

C. The basic shuttle sortie offers the possibility of several desirable modes of experiment operation and support not available for unmanned launches. These include resupply of gases for flow-type X-ray counters, resupply of crygens for cooled detectors, in-orbit check-out and adjustment prior to experiment operation, in-orbit test of new instrument concepts, and some on-the-spot repair of defective instrumentation. For short-duration missions, extensive experiment repair can most expeditiously be carried out by returning the experiment to earth at the conclusion of the mission. The shuttle sortie option removes the difficult requirement to design certain classes of instruments for the long-term storage of consumables.

In the case of servicing and repair, it is assumed that support by EVA will be very limited due to the complexity and hazardous nature of this activity. Therefore, manned involvement could be limited to straightforward EVA operations such as releasing an instrument cover or deployment mechanism which fails to operate properly. Other replacements, adjustments, or minor repair could be limited to portions of the instrumentation which is inside the sortie laboratory, taking advantage of the shirt sleeve environment. In all cases, diagnoses of problems would be carried out in conjunction with ground-based analyses using experiment telemetry and visual assessment by the sortie crew. It is recognized that many classes of failure would require return of the instrument to earth for repair and possible reflight on a subsequent mission.

The shuttle sortie offers the attractive possibility of higher electrical power levels and greater capability for data handling than would be likely to be available otherwise.

The experiments discussed in this appendix make requirements upon the spacecraft which can be satisfied by the basic sortie laboratory and pallet with no additional high-accuracy stability on pointing requirements beyond those provided by the basic shuttle. These missions should be early in the shuttle program and allow observation opportunities while providing laboratory facilities for the development of instrument techniques to be used in the more elaborate follow-on missions.

G

Characteristics

D. 1) 7 to 30 days.

2) Low altitude (100-150 n. mi.) low inclination orbit preferred (<15°).

3) 25 Kbps average with an occasional high bit rate in real time for X-ray experiments.

4) No more than required to allow missions of 30-day durations. The payload specialist will be a senior experiment technician or engineer capable of electronic repairs and modifications for all experiments in flight.

5) 1° pointing; <0.1°/sec jitter rate.

6) Operating temperature range to be -10°C to +30°C for instruments on pallet. Approximately 5 KW average power will be required. (For additional comments, see paragraph seven.)

7)

Instrument energy range	Weight (lb.)	Vol. ($ft.^3$)
0.02 to 2 KeV region	6000	1000
2 to 50 KeV	2000	100
0.05 to 10 MeV	2000	100
>10 MeV	4000	175

This weight is exclusive of sortie laboratory and pallet.

8) Could be used in the event of mechanical malfunction.

9) Need communications capability to correlate measurements in real time with ground-based radio and optical observatories. Committed ground observatories will be required during missions. Internal correlation of observations requires accurate coalignment (0.1°) of instruments and precise timing.

10) On board spacecraft:

1. Several of the experiments will require cryogenic support. (~50°K to 125°K).

2. Aspect sensors capable of reconstructing instantaneous aspect to 0.1° are required.

On Ground:

1. Dedicated computer required at the Mission Ops Center.

11) Documentation comparable to that required for 990 missions, or Explorer type documentation, will support the concept of low cost accessibility to space.

12) Launch window dictated by position of source to be observed. Must be capable of observing a single specific source for a significant portion of the mission or carrying out a sequence of observations of several sources.

13) A. Special efforts are necessary to ensure that radioactive contaminants are controlled and limited.

B. Contamination by spacecraft effluents could seriously degrade the instruments. Solid state detectors, scintillators and optical surfaces are susceptible.

14) Some of the instruments will require isolation from the secondary radiation produced in the spacecraft mass. These instruments weigh several thousand pounds and require that any isolation from the pallet be accompanied by retention of the pointing accuracy shared by the remaining instruments on the mission.

APPENDIX C

X-RAY AND GAMMA RAY ASTRONOMY

APPENDIX C

A. X-RAY AND GAMMA RAY ASTRONOMY

B. POINTED SORTIE MISSION

C. The experiments to be conducted on this type of mission require a platform with a high degree of pointing accuracy and stability (on the order of a few arc minutes).

Characteristics

D. All requirements in this section are identical to those in paragraph D of Appendix B except as explicitly noted.

1) 7 to 30 days.

2) Low altitude (100-150 n. mi.) low inclination orbit preferred ($<15°$).

3) 25 Kbps average with an occasional high bit rate in real time for X-ray experiments.

4) No more than required to allow missions of 30 day durations. The payload specialist will be a senior experiment technician or engineer capable of electronic repairs and modifications for all experiments in flight.

5) Spacecraft shall be capable of pointing to $0.1°$ with $<0.01°$/sec jitter rate. It should be capable of performing limited maneuvers about the target position such as rocking or mini-scans.

6) Operating temperature range to be $-10°$ C to $+30°$ C for instruments on pallet. Approximately 5 KW average power will be required.

7)

Instrument energy range	Weight (lbs.)	Vol. ($ft.^3$)
0.02 to 2 KeV	5000	300
2 to 50 KeV	1000	100
0.05 to 10 MeV	5000	200
> 10 MeV	4000	200

8) Could be used in the event of mechanical malfunction.

9) Need communications capability to correlate measurements in real time with ground based radio and optical observatories. Committed ground observatories will be required during missions. Internal correlation of observations requires accurate coalignment (0.1°) of instruments and precise timing.

10) On board spacecraft:

    1. Several of the experiments will require cryogenic support. (~50°K to 125°K).

    2. Aspect sensors capable of reconstructing instantaneous aspect to 0.1° are required.

    On Ground:

    1. Dedicated computer required at the Mission Ops Center.

11) Documentation comparable to that required for 990 missions, or explorer type documentation will support the concept of low-cost accessibility to space.

12) Launch window dictated by position of source to be observed. Must be capable of observing a single specific source for a significant portion of the mission, or carrying out a sequence of observations of several sources.

13) A. Special efforts are necessary to ensure that radioactive contaminants are controlled and limited.

    B. Contamination by spacecraft effluents could seriously degrade the instruments. Solid state detectors, scintillators, and optical surfaces are susceptible.

14) The inclusion of large X-ray telescopes in this category of mission, coupled with the desire that some instruments be removed from the spacecraft mass, suggests the desirability of raising the pallet out of the shuttle bay.

APPENDIX D

X-RAY AND GAMMA RAY ASTRONOMY

APPENDIX D

A. X-RAY AND GAMMA RAY ASTRONOMY

B. SHUTTLE DEPLOYED SATELLITE MISSIONS

C. The goals and objectives of X-ray and gamma ray astronomy require a series of shuttle-deployed spacecraft. These are required both for long observation times not available on the shuttle and for scanning and survey missions not amenable to shuttle operation. Some of the spacecraft would be dedicated to a single prime experiment; others would be complements of several experiments. The spacecraft requires pointing and stability accuracy to a few arc minutes for X-ray experiments and 0.5° for gamma ray experiments. Power and weights will vary from tens of watts to hundreds of watts and hundreds of pounds to thousands of pounds. The complement of these spacecraft will interface closely with follow-on large observatories. Large observatories are outside the scope of the present working group. We have, therefore, not addressed the specific requirements for deployed spacecraft other than to identify the requirement for their need to complement the shuttle sortie and large observatory modes of operation. The deployed spacecraft would be recovered and refurbished for reuse.

Characteristics

D. All requirements in this section are identical to those in paragraph D of Appendix C except as explicitly noted.

1) 6 months.

2) High enough to achieve required lifetime and ensure recovery. Low inclination preferred (<15°).

3) Up to 25Kbps.

4) None.

5) 1° pointing; <0.1°/sec jitter rate.

6) Operating temperature range to be -10°C to +30°C.

7) Weights from hundreds to about ten thousand lbs.

8) Not applicable.

9) Need communications capability to correlate measurements in real time with ground based radio and optical observatories. Committed ground observatories will be required during missions. Internal correlation of observations requires accurate coalignment (0.1°) of instruments and precise timing.

10) On board spacecraft:

1. Several of the experiments will require cryogenic support. (~ 50°K to 125°K).

2. Aspect sensors capable of reconstructing instantaneous aspect to 0.1° are required.

On Ground:

1. Dedicated computer required at the Mission Ops Center.

11) Documentation comparable to that required for 990 missions, or explorer type documentation will support the concept of low cost accessibility to space.

12) Launch window dictated by position of source to be observed. Must be capable of carrying out a sequence of observations of several sources on command.

13) A. Special efforts are necessary to ensure that radioactive contaminants are controlled and limited.

B. Contamination by spacecraft effluents could seriously degrade the instrument. Solid state detectors, scintillators, and optical surfaces are susceptible.

14) None.

APPENDIX E

MINUTES OF FIRST X-RAY ASTRONOMY GROUP

APPENDIX E

MINUTES OF FIRST X-RAY ASTRONOMY WORKING GROUP

Attendees: A. Opp, NASA HQ, Chairman
C. Fichtel, NASA/GSFC, Co-Chairman
S. Holt, NASA/GSFC, Secretary
A. Jacobson, JPL
J. Trainor, NASA/GSFC
C. Dailey, NASA/MSFC

Organization: The present group is envisaged as the nucleus for an on-going advisory group to include extra-NASA personnel. During the next year, the group will be enlarged to include a representative sample of the X-ray and gamma ray communities to assist NASA in planning the effective utilization of the Space Shuttle.

Purpose: The objectives of the group for this meeting are the identification of the scientific tasks and the role of SORTIE in their accomplishment. Emphasis on cost-plus-science optimization was given by Dr. Low, and should reflect the efforts of this group.

Background: SAS-A-C, OSO-F-I, UK-5, ANS, and HEAO-A-B are to be considered pre-shuttle science as a baseline scientific background. The role of HEAO-C, HEAO-D and follow-on space observatories were the subjects of discussion during the meeting. The working group concluded that the short exposures in the basic sortie mode could not fulfill all of the objectives of the discipline and that a free-flying spacecraft was necessary for a balanced research program. It was assumed that HEAO-C would be launched in 1978/1979 and HEAO-D in 1981/1982. The working group considered a complement of large gamma ray experiments to be appropriate for HEAO-D. Revisits and refurbishments of both vehicles are planned in the 1980's.

GENERAL REQUIREMENTS FOR SORTIE WHICH ARISE FROM THE SCIENTIFIC OBJECTIVES

The following discipline-peculiar requirements were identified:

1. Orbit altitude: charged particle background considerations require as low an orbit as possible. Altitudes of 100-150 n. mi. are ideal for X-ray and gamma ray astronomy.

2. Orbit inclination: to minimize charged particle background, as low an inclination as possible is desired (equatorial is ideal). It was understood that an equatorial orbit may not be commensurate with the envisaged shuttle capability, and, further, that a low-inclination orbit is not compatible with the requirements of cosmic ray investigators. Adequate data was not available to generate a reasonable value for a "maximum" inclination, but the consensus was that an inclination of less than $\sim 15°$ was desirable.

3. Pointing accuracy and stability: some experiments in the discipline, particularly in low-energy X-ray astronomy, require better pointing and stability than available in the basic sortie. For this reason, we have divided the missions into two groups — those requiring pointing accuracy of $\sim 0.1°$ or better and stability of $\sim 0.01°$/sec, and those which can be accomplished with numbers an order of magnitude larger. Aspect must be reconstructable to $\leqslant 0.1°$ for the coarse-pointed missions and $0.01°$ for the finer pointed missions (i.e., an order of magnitude better than the pointing accuracy). It was concluded that small thrusters should be recommended for shuttle. Holding the basic coarse pointing of $\sim 1°$ over seven days with the main thrusters could take as much as 2500 lbs. of hydrazine. For the fine-pointed missions, RCS systems would not be advisable.

SHUTTLE-UNIQUE OPPORTUNITIES

It was concluded that there are many unique advantages which accrue from a sortie launch (and possible revisit) as opposed to a more conventional launch platform. The only real disadvantages would appear to be short exposures and a pointing capability which must be developed for the more sophisticated missions. The unique advantages are:

1. The ability to do experiments which have inherently short lives due to the use of consumables. These include things like cryogenics, proportional counters with windows so thin that gas leakage is large, photographic film, and nuclear emulsions. Such experiments may be refurbished after one flight and reflown as required. As a serviceable mission is essential for success of this type of experiment, these should be considered as especially suited for sortie.

2. The avoidance of weight, power, and volume constraints inherent in present launch vehicles. Constraints of weight, power and volume are prime factors in increasing the cost of scientific research in space.

3. The ability to use laboratory-class digital electronics and telemetry encoding equipment due to the easement of size restrictions and the laboratory

environment of the sortie can. This should result in tremendous cost savings, as this equipment need not meet tight QA specifications and can be modularized and repaired in the sortie laboratory. The use of NIM and CAMAC equipment is especially desirable.

4. Quick turn-around for instrument development and goal-oriented experimentation. The modularization of the electronics in the SORTIE can and the refurbishment and refly opportunities allow for the logical development of large experiments in multiple SORTIE missions and the quick response to new scientific requirements. Experiments can be changed between missions to respond to these new requirements and can even be changed in orbit by changing electronic logic in the SORTIE can, if required.

SORTIE PHILOSOPHY

Several specific recommendations for the conduct of the discipline were decided upon.

1. Maximization of electronic equipment within the sortie can (laboratory atmosphere). If the sensors and only that equipment which is necessarily close to the sensors (e.g., high voltage, supplies, pre-amplifiers) are kept on the pallet, all of the digital and encoding logic can be kept in the SORTIE laboratory.

2. The use of standard modules (NIM and CAMAC) can result in substantial savings and interface simplicity. Experiment logic can be easily changed and repaired, and a large degree of commonality among all experiments can be maintained.

3. EVA should be discouraged, in general, as the experiments will be cheaper and the interfaces less complicated without EVA. Only in the event of a mechanical failure which can be easily corrected on the pallet is EVA to be considered.

4. The number of personnel should be minimized in order that the sortie missions have the longest possible lifetimes. The use of modular electronics should make experiments serviceable by senior technicians and engineers who are not necessarily experiment-dedicated (i.e., there need not be as many as one technician for each experiment).

5. The use of relay satellites is strongly recommended in order to maintain contact with the mission at all times during the short duration of the mission. Experiment evaluation will be accomplished grossly via display in

the sortie lab (experiment furnished), and more carefully via real-time analysis using computers at the mission control center. Steps to correct any fault quickly can then be instituted via direct voice link between the mission control center and the sortie laboratory.

6. A payload dedicated 8 KW fuel cell should be planned as the 1-3 KW discussed as available to experiments will probably be insufficient for most of the conceived missions.

7. Steps should be instituted to reduce the acoustic noise level to below 120 dbm in order that standard laboratory modular electronics (as well as pallet equipment) not become inordinately expensive to comply with the current acoustic levels.

SUB-DISCIPLINE COMPATIBILITY

Several sub-discipline peculiar points were raised which should be considered in defining specific missions.

1. X-Ray astronomy (i.e. < 50 KeV) will be moving out of the survey mission category and into the era of specific objective experiments by the time of the sortie. Gamma ray astronomy, however (i.e. > 80 KeV), is still expected to require survey missions in the 1980's.

2. X-ray astronomy experiments exist which can be accomplished without precise pointing [e.g. temporal studies using large banks of proportional counters, high resolution spectral investigations for Fe line emission and others utilizing Si (Li) detectors]. These should be considered for the early SORTIE missions.

3. Effort should be expended to substantially increase the sensitivity of gamma ray astronomy experiments in view of the small fluxes expected. In addition to developments unique to a specific experiment, the SORTIE vehicle should have a minimum impact on this sensitivity via controlled radioactive contamination and, ultimately, the ability to isolate large low energy gamma ray experiments from the sortie vehicle via extensible booms.

4. X-ray astronomy experiments which require pointing (e.g., grazing incidence telescopes, dispersive spectroscopy, polarimetry) should be included in the mission program for specific objectives when the pointing capability exists. These experiments are important, and their inclusion in the program determines the requirement of a pointed pallet. It must be

borne in mind, however, that such precise pointing is not required for all aspects of the discipline, as noted in the report.

5. An overlap in sensitivity of instruments should be encouraged for the most effective correlative analyses. The scintillator-solid-state detector low energy gamma ray experiments should overlap the energy range of the proportional counter and solid-state X-ray instruments and the spark chamber gamma ray instruments at higher energies.

OVERALL SCHEDULE

The suggested scheduling in the report (4 missions/year) is a result of the anticipated desire for participation in the program of all the institutions having active research programs in X- and gamma ray astronomy. To a large extent, the later scheduling will depend upon the availability of large satellites for the discipline (e.g. refurbished HEAO's and super HEAO's). The realization of a large X-ray telescope in 1989, and the need for earlier large-orbiting observations in the 1980's are important considerations in determining the SORTIE requirements during the same time frame. The consensus of the committee was that large (HEAO class and larger) stabilized platforms and Shuttle SORTIE Laboratories are both necessary for the accomplishment of all its objectives.

C5

APPENDIX F

WORKING GROUP REPORT FORMAT

APPENDIX F

1. Discipline area

2. Outline the goals and objectives for the discipline for the decade of the 1980's.

3. Identification of the potential contributions the sortie mode can make to specific discipline goals and objectives.

   a.

   b.

   c.

   etc.

4. Descriptive title of sortie mission or missions required for each of the potential contributions listed in #3 above (not necessarily all different).

   a.

   b.

   c.

   etc.

5. Descriptive titles of sortie missions for which requirements and characteristics are outlined in attached appendices.

   a.

   b.

   etc.

6. Outline of the proposed total flight schedule of sortie and non-sortie missions needed to meet the discipline goals and objectives.

   1979
   1980
   1981
   1982
   1983
   1984
   1985
   1986
   1987
   1988
   1989
   1990

APPENDIX F

A. Discipline area

B Sortie descriptive title

C. Reasons the sortie mode would be preferred over other methods for each of the potential contributions of this type sortie mission given in #4.

D. Requirements this type mission places on the shuttle if the potential contributions are to be realized.

(1) Length of flights

(2) Orbit

(3) Data requirements

(4) Role and number of personnel in orbit

(5) Stabilization and pointing

(6) Power and thermal

(7) Weight and volume

(8) EVA requirements

(9) Correlative measurements

(10) General support equipment

(11) Documentation requirements

(12) Special operating constraints

(13) Contamination requirements

(14) Other

E. Policies and procedures which must be changed or instituted to fully exploit the shuttle sortie mode and reduce the cost of research in space.

F. Brief description of estimated magnitude of sortie mission user community.

G. Recommended approaches for interfacing with the user community.

H. Recommendations on future actions required to implement the sortie mission including SRT, studies, and future planning activities.

PRELIMINARY REPORT OF THE UV-OPTICAL ASTRONOMY PANEL

CONTENTS

	Page
INTRODUCTION	13-1
SUMMARY	13-1
BACKGROUND AND PERSPECTIVE	13-2
RATIONALE FOR THE USE OF THE SORTIE MODE	13-5
SCIENTIFIC OBJECTIVES	13-7
DESCRIPTION OF INSTRUMENTATION	13-11
SHUTTLE REQUIREMENTS	13-18
MAN'S ROLE – EXPERIMENT MANAGEMENT	13-20
FACILITIES REQUIRED	13-21
USER PARTICIPATION	13-24
SRT/STUDY REQUIREMENTS	13-25
COMMONALITY WITH OTHER DISCIPLINES	13-27
POTENTIAL PROBLEMS AREAS	13-28
COST EFFECTIVENESS	13-29
APPENDIX A NORMAL AND HIGH-TIME RESOLUTION PHOTOMETRY	13-A-1
APPENDIX B HIGH ANGULAR RESOLUTION ULTRAVIOLET AND VISUAL IMAGING	13-B-1

CONTENTS (Continued)

	Page
APPENDIX C EXTENDED NEBULAR PHOTOGRAPHY ON SHUTTLE SORTIE MISSION FLIGHTS	13-C-1
APPENDIX D UV SURVEY CAMERA	13-D-1
APPENDIX E STRATOSCOPE III	13-E-1
APPENDIX F SMALL STABILIZED ASTRONOMY PAYLOADS	13-F-1
APPENDIX G MEDIUM AND LOW RESOLUTION ASTRONOMICAL SPECTROSCOPY	13-G-1
APPENDIX H MINUTES OF PRELIMINARY MEETING	13-H-1
APPENDIX I REFERENCE MATERIAL USED BY GROUP	13-I-1

PRELIMINARY REPORT OF THE UV-OPTICAL ASTRONOMY PANEL

PANEL MEMBERS

N. Roman, HQ, Chairman
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INTRODUCTION

The members of the working group were selected to represent each of the NASA centers concerned with space astronomy either as a field of research or in a direct support function. Similarly, the group was selected to balance an active interest in astronomical research with a background in the engineering required to support such research in space. As a means of becoming acquainted and of developing into a coherent group and as a means of making the workshop itself more productive, the panel met at Goddard Space Flight Center on July 18 and 19, 1972. During this meeting many general issues were discussed, and the members were given individual written assignments to bring to the workshop. These were distributed on the first day of the workshop so that they could be read before the Tuesday session to form the basis for most of the work of the panel during the week.

Early in the first meeting, the extended definition of the sortie mode was discussed. The panel members decided that the tasks involved in treating the seven-day mission with attached instruments were, in themselves, sufficiently large for the time involved and that we should concentrate on these and ignore all other uses of the shuttle except to confirm our interest in using the shuttle in all modes.

SUMMARY

The working group for UV-Optical Astronomy has concluded that the 6-30 day Shuttle Sortie Lab research mode affords unique opportunities and capabilities. The classes of scientific programs most suited to this mode are those requiring the high information content of photographic film and those of well-defined scope requiring a limited amount of observations from above the earth's atmosphere. Absolute flux determinations for selected stars, UV wide angle sky surveys,

studies of large fossil Stromgren spheres, and astrometry of clusters are but a few of the programs which would qualify. That man can accompany the experiments can be reflected in lower costs for simplified instrumentation, versatility and flexibility in programming, and probably, higher reliability and scientific return. However, to be effective, enough men must be present; an experiment crew of 4 is highly desirable.

Mission efficiency will be enhanced by operating several experiments simultaneously during a single mission. The added operational complexity should be easily managed by a control computer with manual interrupt by on-board or ground-based personnel. This operational mode as well as specialized requirements, including low contamination levels, and vibration levels, accurate pointing and guidance (low jitter), multi-slew operations for optimum nighttime usage, all argue for a dedicated Astronomy Lab. This lab takes on the aspects of a facility where, as on the ground, users may mount their own telescopes, attach specialized instruments to the facility telescopes, or make use of existing instruments or data gathered by other experimenters. The number of such dedicated missions per year profoundly influences the types of programs which can be performed, the cost effectiveness, and, indeed, the usefulness of the mode itself. Three flights per year are recommended. The option to use small automated instruments on flights of opportunity with other disciplines' labs also should be maintained.

For maximum effectiveness and breadth of use, experiment management procedure must be streamlined. Short lead time for experiment development, minimum documentation, use of standard components where possible, and the assumption of responsibility for experiment success by the experimenter are imperative. The shuttle managers should have responsibility only for the operation of the vehicle and for maintaining high standards of safety. An adequate dedicated communication link is necessary to allow astronomers on the ground to work with those in orbit. Both up and down links for picture transmission are needed.

In keeping with the facility concept, a wide user community should become involved in the planning of the sortie lab at the earliest possible time.

An active and continuing dialogue must be established and maintained between members of the astronomy community and the sortie lab and shuttle designers.

BACKGROUND AND PERSPECTIVE

The working group began its task by discussing the major anticipated programs for the late 1970's and early 1980's. It was agreed upon at the outset that the

shuttle sortie mode should be but one aspect of a balanced overall program to affect research in astronomy. The group attempted to appraise the unique capabilities and limitations of this research mode. They considered how it could benefit by study efforts and technological developments sponsored by the other programs and, more explicitly, how the shuttle sortie operation compares to that for the current airplane program involving the Lear Jet, the CV-990 and the C-141. The results for the last effort are described in later sections of this report.

The active research programs should include the following:

ROCKETS CLASS PAYLOADS

As the shuttle becomes fully operational, some of these payloads can be expected to be launched and ejected by the shuttle, some will form a class of experiments hard mounted on a stabilized platform within the shuttle, while the remainder will be handled in current fashion. The "disposable" satellite class of freeflyers will be built inexpensively and with lifetimes measured in days. Small aperture instruments mounted on the shuttle will be discussed to some length in this report. Rocket launched payloads will include those used for observing highly transitory phenomena and single rare events, for developing and testing new specialized instruments, for validating results, etc.

BALLOONS

As the balloon program in UV-Optical astronomy is expected to be largely displaced by shuttle launched experiments, little time was spent discussing this area.

EXPLORER AND OBSERVATORY CLASS INSTRUMENTS

A special effort was made by the working group to establish the roles of the IUE and the LST and to scope the shuttle sortie mode in this context. The IUE is recognized as an efficient instrument for obtaining high volume spectroscopic data for many months for both normal and for variable stars. As currently proposed, the LST is a superior instrument for narrow field imagery, for the detection and study of faint sources, and for high resolution spectroscopy. It was assumed that both would be fully operational prior to the flights of the astronomy sortie laboratory and that the objectives of the sortie lab should not merely duplicate those of either. It is clear that even with an LST, IUE and an Astronomy Sortie Lab, a number of scientific programs can be identified which can be most

effectively performed using long-lived explorer class instruments. In addition to spectrometry as provided by IUE, photometry and possibly polarimetry are general techniques which will maintain their importance to space astronomy for many years. Of course, as the entire field of astronomy advances and new discoveries are made (and there is no reason to believe that the plethora of discoveries made in the 60's is a unique occurrence), new observational programs will be indicated which impact the Explorer program.

Many studies and much developmental work can directly benefit the shuttle sortie mode. Among these are the following:

- Guidance and stabilization designs for the IUE and LST
- Advanced sensor work in support of these above programs as well as others (including the Earth Resources Sensor Work)
- Technological developments in producing low scattering optical surfaces for the LST
- The ST100 stabilized platform design by MSFC for handling small instruments remotely (as a precursor to satisfy a clear need with the shuttle)
- Studies and designs for the high spatial resolution telescope for the Stratoscope III project
- Design of the IR telescope mounting for the C-141 project

Much of the above work can be synthesized to effect cost savings in the development of a sortie lab for astronomy by eliminating duplication of design. Observing programs should be and can be uniquely defined, but some overlap with other programs is highly desirable for validation and confirmation of results and for obtaining correlative data.

Finally, it was decided that in addition to the ongoing flight programs and study and design efforts, the peculiar programmatic aspects of the shuttle sortie impact the scientific programs. The limited flight duration and low frequency of flights are significant constraints to the achievement of the scientific objectives and the selection and design of realistic programs.

RATIONALE FOR THE USE OF THE SORTIE MODE

Certain advantages can be gained by mounting experiments aboard the shuttle, some of which are not unique but for completeness are included as a comprehensive base for the formulation of typical scientific programs.

OBSERVATIONAL ADVANTAGES

Multiple advantages accrue from using instruments in spacecraft above the earth's atmosphere. The ultraviolet wavelength domain, normally inaccessible due to atmospheric absorption, becomes accessible. Image degradation commonly referred to as "seeing" is eliminated. Limiting high spatial resolution is restricted only by optical aberrations and guidance instabilities. Scintillation noise which interferes with the study of high speed brightness fluctuations is eliminated. This represents also a major source of noise in spatial (Michelson) interferometry. The background light level, a source of noise, is reduced markedly. (Some increase in particle radiation may offset this gain.) No meteorological changes interfere with the study of variable phenomena and extended exposures are possible.

OPERATIONAL ADVANTAGES

Operational advantages of the shuttle sortie provide:

Round Trip Capability — Instruments may be updated and refurbished; designs may evolve with experience. This can result not only in substantial cost savings but increased scientific return. Systematic errors are eliminated, calibrations perfected, and data becomes more trustworthy. Abort capability provides a second chance. The possibility of utilizing returnables and expendables must be recognized as affording a complete new approach to effect scientific programs above the earth's atmosphere. It is well recognized that exceedingly high information content can be achieved by the return of data stored, for example, in photographic form rather than relying on data links, without resorting to excessively wide bandwidth communications systems. The use of short lived expendables, such as cryogenics for cooling detectors, is also feasible.

Liberal Size and Weight — Provisions of the shuttle allow for the design and use of ruggedized, but not weight optimized instrumentation. Cost savings should follow while reliability is increased. Reduction in constraints leads to a simplication in instrument design and will facilitate participation by non-NASA experimenters.

Interfacing — Man interfaces directly with the instruments. Adaptability and flexibility are thereby provided which can translate into increased scientific return. Changes to instrument settings or observing sequences which cannot be anticipated or therefore pre-programmed can be made in situ. Minor repairs made during flight might well save the experiment. Several examples from recent failures in both the satellite and rocket programs can be used to validate this point. The degree of automation of instrumentation can be relaxed which, in turn, increases the level of standardization which becomes feasible. It is clear, however, that most if not all these advantages are lost if man does not have some form of access to the instruments.

Availability — Immediate availability of data is provided. Target acquisition, exposure levels, and even preliminary results based on pre-processing can be utilized for program optimization through the man interface mentioned above. The peripheral instrumentation to perform these functions can be accommodated in the large payload weights. Instruments may be calibrated on the ground and in flight. Thus preflight, post flight and in-situ measurements can be used as experiment controls. One novel possibility is to use the shuttle to launch a subsatellite to facilitate the in-situ calibration.

Because of the constrained flight duration and frequency these above advantages can be realized efficiently only for certain programs. Several broad classes of inappropriate programs can be identified. For example:

a. Programs requiring excessively long exposures and by implication superior guidance stability;

b. Programs concerned with very faint sources which would require the use of large aperture telescopes;

c. Programs which are essentially open ended in that many separate observations for many objects are needed. Routine photometric monitoring of classes of variable stars and spectroscopy for establishing population characteristics are such program examples;

d. Programs which do not utilize the advantages afforded by mounting instruments above the atmosphere.

Program classes a and b, for example, are more efficiently pursued by means of an LST type instrument. Program class c is more suited for either the LST or the Explorer series of satellites. The working group tested possible generalized program categories against these criteria. These categories (as outlined under Scientific Objectives) appropriately exploit the various operational modes

made possible by the shuttle. In addition to the limited purpose programs (Category 1) and specialized programs (Category 2), exploratory programs (Category 3) will attempt to ascertain the feasibility of mounting a full scale instrument/program for further investigation and allow for optimized planning of the expanded program. Correlation and Validation programs (Category 4) use the shuttle sortie for a direct confirmation of unexpected results obtained by, say, a free-flying observatory. It was not the intention of the working group to correlate specific missions with a single category. In fact, a mix of programs/categories for each mission will probably maximize the scientific return and make most efficient use of the sortie mode. Some of the objectives referred to might be achieved on flights shared with other disciplines but only a "dedicated" astronomy laboratory will allow the simplification of interfaces, proper calibration, control of noise and contamination, and the most efficient use of the trained specialist aboard the shuttle.

SCIENTIFIC OBJECTIVES

The working group has identified a number of scientific program objectives which are highly suited for the sortie mode of operation. In its deliberation, the group was conscious of cost, but did not consider it appropriate to overemphasize it or use it to constrain the formulation of reasonable programs. Broad scientific areas were first delineated. Following this, individual panel members considered in detail specific areas and prepared assignments describing characteristic scientific programs; these individual assignments are given as Appendix H to this report. They formed the basis for the formulation of a realistic list of requirements for instrumentation, operational procedures, and facilities on board the orbiter and on the ground. These efforts represent a best effort attempt to define experiments for the significantly distant future and the list is not comprehensive. In particular an extra effort was made to avoid merely listing all possible programs in general terms. The following programs are listed in terms of the categories defined above.

CATEGORY 1

UV Broad Band Survey/Spectral Survey

The objectives of these programs are to secure a multiband ultraviolet photographic atlas of the sky (equivalent in quality to the Palomar Survey) and a low resolution spectral survey equivalent in the ultraviolet to the standard Henry Draper catalogue. These are well defined programs which require only limited observing time. The shuttle sortie mode permits the use of photographic recording and storage of the data, an overriding consideration for achieving high

quality data in limited time. This data will be important for correlative purposes for LST, it will greatly extend the work begun by Celescope, and the instrumentation will be useful for further studies of extended sources. Among the latter uses, the search for intergalactic bridges can be mentioned.

High Spatial Resolution Photography

Speed, precision and dynamic range can be obtained by using electronographic and other modern photographic techniques with high performance optical systems. A number of programs utilizing essentially the same instrumentation are described below.

Cluster Photometry — Multi-band observations covering the ultraviolet and visible can provide color-magnitude diagrams of selected open and globular clusters and associations. These data are important for stellar evolution studies, searches for new variables near the centers of dense clusters and for investigating fine structure in the interstellar medium in the immediate cluster environs.

Astrometry — Precise positions for selected objects can be obtained by capitalizing on the high image quality and comparitively wide field capabilities of the proposed instrumentation. Representative programs include the determination of distances to several clusters, e.g., the Hyades, by the method of trigonometric parallaxes, measurement of the proper motions of classes of objects in order to establish population characteristics, and the measurement of nearly resolved astrometric binaries. For the last case, photometric (possibly spectroscopic) classifications for the fainter components may be obtained. Clearly these objectives will require not only multiple missions but also judicious spacing of the sorties.

Extended Source Photographic Photometry — The high angular resolution, coupled with the wide angle field of view unimpeded by atmospheric emission and scattering, will facilitate narrow wavelength band observations of extended sources for the purposes of studying the morphology, temperature and density fluctuations in nebular sources. The addition of, say, a Fabry-Perot interferometer would permit the studies to include the dynamic motions of the material.

Calibration and Stellar Standards

By taking advantage of the return capability of the shuttle as well as its liberal size and weight constraints, a program to establish a network of standard stars becomes highly feasible. Current attempts to obtain absolute flux measures from rocket observations are frustrated by one or more of the following; lack of exposure time, inability to perform any post calibration, transfer of source standards from laboratory environment to in-situ situation, difficulty of

performing calibrations at full aperture and the limited region of the sky which can be observed in a single flight. The use of a sub-satellite in which a standard source is mounted can provide in-situ full aperture calibration with a source observed in the same manner as the stars. A widely spaced network of flux standards can thus be established for the secondary calibration of instruments located both on the ground and in space (e.g., the LST). Furthermore the basic measurements will provide high quality input for the comparison with detailed, modern, stellar atmosphere models.

CATEGORY 2

The requirements for instrument accessibility and quick data retrieval are acute in this category of specialized programs. Some representative objectives are described below.

High Time Resolution Photometry of Stars

An example is the study of flare stars and pulsars. Such data in the ultraviolet may provide a basis for elaborating pulsar models particularly in those cases where the x-ray and radio data are inconclusive. The capability afforded may also be used profitably to probe the atmosphere of planets by observing stellar occulations. Indeed the same technique is applicable for the study of the earth's atmosphere and hence commonality of instrumentation and general needs with planetary astronomy and aeronomy should be noted. Time resolution of the order of 5 microseconds is considered nominal.

Peculiar Objects/Variable Stars

Time resolved ultraviolet photometry and/or spectrophotometry can provide information on chromospheric structure and activity in variable stars such as in certain eclipsing variables systems at critical phases. These programs can be time consuming and usually require tight scheduling; hence they may be appropriate as targets of opportunity but the instrumentation requirements are essentially the same as for the high time resolution program. A group of basic auxiliary instruments can be used in a large number of scientific programs as time is available or current interest dictates. Additional examples which depend on the quick reaction which should be possible with the shuttle include the study of comets, novae and supernovae.

Stellar Interferometry

In the area of stellar interferometry, the absence of atmosphere scintillation improves the signal-to-noise ratio by improving the coherence of the two

channels. Two methods have been considered for the direct measurement of stellar diameters; the measurement of fringe visibility photoelectrically using widely space apertures, and the use of an occulting knife edge. Both require highly specialized instrumentation, critical alignment or adjustment during operation and special data recovery and control techniques. Vibration and general noise of the shuttle may interfere with these experiments.

Far UV Spectroscopy

Grazing incidence instrumentation will be required to investigate the far ultraviolet wavelength region where the spectrum is expected to be dominated by the highly energetic transitions, occuring within stellar coronae. The number of sources sufficiently "bright" or equivalently suffering low absorption by the interstellar medium is unknown at this time, but proposed rocket and satellite experiments (OSO J) should provide some of this necessary background information.

Extended Nebular Photography

In contrast to the program described under the Category 1, these scientific objectives require exceedingly wide fields of view (near 90°). These very fast but not necessarily large camera systems can search for fossil Strömgren spheres similar to the Gum Nebula and HII regions heated by cosmic rays, study supernova shells for confirmation of blase wave excitation models, and search for extragalactic bridges. Small automated cameras can be mounted on the type of platform referred to in "Background & Perspective" of this report such as the ST 100 platform designed for the Apollo program. The program is suitable for early sortie lab flights and early results would probably suggest important new program directions.

CATEGORY 3

Although we have included only two examples of programs in this category, it is clear that as various observations are made, both from the shuttle and in automated flight programs, a continuing succession of new observational programs will become evident. The shuttle provides unique, low cost experience on which to base the design of advanced, large scale experiments.

UV Polarimetry

Recent observations with a rocket borne polarimeter have shown that the interstellar medium may exhibit unusual polarimetric properties as a function of wavelength. Further, circular polarization intrinsic to stars and to the interstellar medium has been detected by ground based instrumentation and is

evidence for the interaction of material and intense magnetic fields. In this field of renewed and redirected interest, which bears directly on our understanding of the interstellar medium, exploratory observations made with simplified instrumentation could be used to determine the importance of a full scale observing program with an Explorer class satellite.

High Time Resolution Spectroscopy

Recently, time variability in the emission features in some hot stars (Be stars) has been detected on time scales ranging from months down to minutes. Study at the latter time resolution requires a specially designed instrument and, probably data pre-processing and compression. As for the polarimetry, the Shuttle Sortie Laboratory can be used for exploratory measurements to assess the scientific potential in this research area.

CATEGORY 4

In this category the multiple instrumentation capability and the flexibility and rapid reaction time of the sortie mode is utilized to obtain those observations which would confirm or clarify questionable observations.

DESCRIPTION OF INSTRUMENTATION

From the foregoing material it is evident that a dedicated astronomy sortie laboratory must provide both a selection of basic facility instruments useful for many kinds of research programs and provisions for mounting, pointing and operating small, specialized flight-of-opportunity instruments. The instrumentation outlined below satisfies the requirements of the representative scientific programs discussed under "Scientific Objectives" and would be of obvious benefit in many other research areas. However, it should not be considered to be exhaustive.

We envision the use of three classes of light gathering instruments: "rocket class" instruments of aperture ≤ 0.4 meters, wide-field survey telescopes 0.5 - 1.0 meters in aperture, and a 1.0 - 1.3 meter high spatial resolution telescope. General purpose auxiliary equipment includes a high spatial resolution camera plus selected filters, a medium to low spectral resolution spectrometer, a photometer with high time resolution capability and a polarimeter. Airlocks and small stabilized platforms will facilitate the mounting and operation of flight-of-opportunity or special purpose instruments.

Typical instrument specifications are given below. Constraints on pointing, jitter and drift rates refer to ultimate scientific requirements. These may be achieved by some combination of baseline constraints on the orbiter (see "Shuttle Requirements" which follow) automatic internal guiding provided by the instruments themselves, and manual guiding by the observer. Specifications for the most part do not include sizes, weights, etc., of auxiliary equipment such as computers or guidance systems. Except for small instruments mounted on stabilized platforms on the pallet, manned access to the focal plane is assumed in all cases.

"ROCKET CLASS" TELESCOPES

Primary light collector: $\leqslant 0.4$ m

Size: $\leqslant 0.75$ m diameter, $\leqslant 1.5$ m length

Weight: 10-50 kgm

Focal Ratio: as fast as f/1

Spatial Resolution: 3 arc-second to 2 arc-minutes

Field of View: 1 - 45 degrees or wider

Pointing Accuracy: ± 0.002 degrees with manual offset guiding, ± 0.1 degrees with automatic guiding

Jitter: ± 3 arc-second deadband

Drift: 6 arc-second/hour

Mounting: Stabilized platform on pallet, stabilized platform extended through airlock or rigid mounting to airlock

Power: $\leqslant 5$ watts average, $\leqslant 15$ watts maximum per instrument

Thermal Requirements: Undetermined but probably less severe than for larger instruments

Mode of Use: Multiple instruments per flight

Sample Program: Extended nebular photography - extragalactic imaging mission might use four cameras per flight, one for visible, three for UV bandpasses.

WIDE-FIELD SURVEY TELESCOPES

Primary Light Collector: 0.5 - 1.0 m

Size: 3.5 - 4.5 m length, 1.0 - 1.5 m diameter

Weight: 500 - 4000 kgm

Focal Ratio: f/2 - f/3

Spatial Resolution: 2 - 3 arc-second

Field of View: 6 - 10 degrees

Pointing Accuracy: better than 0.1 degrees

Jitter: ± 0.5 arc-second deadband

Drift: 4 arc-second/hour

Mounting: Mounted on pallet or laboratory with access for film changes through airlock

Power: < 100 watts

Thermal Requirements: Undetermined

Mode of Use: up to three instruments per flight

Sample: photographic UV spectral survey

HIGH SPATIAL RESOLUTION TELESCOPE

Primary Light Collector: 1.0 - 1.3 m

Size: 2.0 m diameter, 4.0 m length

Weight: 4000 kgm

Spatial Resolution: ≃ 0.1 arc-second

Field of View: 0.5 degree

Pointing Accuracy: 0.01 degrees (or 1.0 arc-second if commonality with planetary studies is desired). Offset guidance mechanism integral part of telescope.

Jitter: ± 0.05 arc-second deadband

Drift: 0.1 arc-second/hour (possible manual correction)

Power: 500 watts

Thermal Requirements: Undetermined but obviously rigid for work at highest spatial resolutions

Mounting: For example, on air bearing through eight foot hatch at end of sortie lab, coude focus accessible to observer (air bearing allows orientation of telescope about the bearing axis and insulates instrument from background vibration and instabilities)

Mode of Use: versatile facility instrument, to be flown on most missions

Sample Programs: Astronomy, electronographic imaging and photometry of star clusters and associations, high time resolution photometry of star occultations by planetary atmospheres, high time resolution spectroscopy of stellar chromospheric activity, intermediate to low resolution UV spectrophotometry of stars brighter than 13 mag.

AUXILIARY INSTRUMENTATION

Medium and Low Resolution Spectrometer

Spectral Resolution: 1 - 10 Å

Configuration: image tube echelle spectrograph for 1 Å mode, remove one grating for 10 Å mode, for use primarily with high spatial resolution telescope. Provision for mounting linear array detectors for high precision spectrophotometry.

Data Storage: electronic recording and readout to preserve high photometric accuracy.

Power: 25 watts (spectrometer), 50-75 watts (ancillary computer)

Thermal Requirements: area of telescope and attached instruments should be free of large thermal transients (10° thermal imbalances) and held to the range 0°C to +40°C if at all possible.

Guidance Requirements: more than adequate guidance provided for high spatial resolution telescope.

Weight: 100 kgms

Volume: $0.5\,m^3$

Sample Program: establish network of calibration standard stars spectrophotometry of peculiar variables, comets, novae, etc.

Normal and High Time Resolution Photometers

Time Resolution: 5μ sec minimum.

Configuration: broad-band filter photometer attached to high spatial resolution telescope or to smaller instrument.

Guidance: Possible manual offset guidance required in crowded fields, where small entrance aperture is used. ± 1 arc-second or better stability required in this mode.

Power Requirements: $\simeq$ 8 watts

Thermal Requirements: Detector area maintained at $<0°C$

Weight: <25 kgms

Volume: $< 1/2$ meter^3

Sample Programs: High time resolution photometry of pulsars, flare stars, stellar occultations by planetary atmospheres, etc.

High Spatial Resolution Camera

Spatial Resolution: 0.1 arc-second - matched to telescope

Configuration: normal or electronographic camera with nuclear emulsion film and interchangeable filters attached to high spatial resolution telescope.

Guidance: Pointing, jitter and drift identical to high spatial resolution telescope constraints. Some provision for image motion compensation by internal electron optics.

Power Requirements: 50 watts

Thermal Requirements: stabilized temperature to insure high image quality. Low temperature coolant necessary for emulsic .

Weight: 50 - 100 kgms

Size: 0.5 - 1.0 m^3

Sample Programs: trigonometric parallax of Hyades, cluster photometry, photometry of visual binaries components, etc.

The mounting, pointing and control of the small instruments defined in A above and of flight-of-opportunity experiments can be facilitated by use of a small, stabilized platform. The stabilized platform should be able to point at least ±45° from vertical with ±0°.1 pointing accuracy, ± 3 arc-second deadband jitter and a drift rate no greater than 6 arc-seconds/hour. It may be mounted on the pallet and operated in a semi-automatic mode, without observer access, or it may be extended through an airlock within the sortie lab, so that observer access becomes possible. In either mode the sortie lab must provide electrical connections for command functions, power, and inertial reference information. To allow simultaneous operation of several such platforms or of other instruments a small processing computer will be essential. Such a computer will utilize inertial pointing information from the orbiter, perform real-time coordinate transformations and deliver pointing commands to the platform. It may also be useful for purposes of inputting simple block encoded command sequences to experiments mounted on the platform. Manual interrupt for updating pointing (correcting for drift) or changing observing sequences will be a necessary capability. It may be anticipated that this platform will be useful to many disciplines and generalized design and interfacing studies are in order.

Manned access to astronomical instruments (at least to focal planes of major telescopes) may be achieved most readily by use of airlocks (vacuum locks). At least two airlocks no smaller than 30 inches diameter should be mounted in the sortie lab (oriented perpendicular to the pallet floor). For the primary telescope it is suggested that an airlock should be mounted in the eight-foot hatch at the end of the lab facing the pallet. Through this airlock the light paths of the largest telescopes to be carried in the payload may be extended into the sortie lab. Possible configurations of the sortie lab, pallet, and airlocks with instruments in place are illustrated in Figure 13-1 and Figure 13-2. Although a single instrument is shown mounted at the Nasmyth focus, an alternate scheme could have a mirror turret arrangement for diverting the beam to any one of several instruments mounted in a radial fashion. Note that the scheme described above strongly resembles that being used for the C-141 telescope and operational results with it will be useful for evaluating the effectiveness of the mounting.

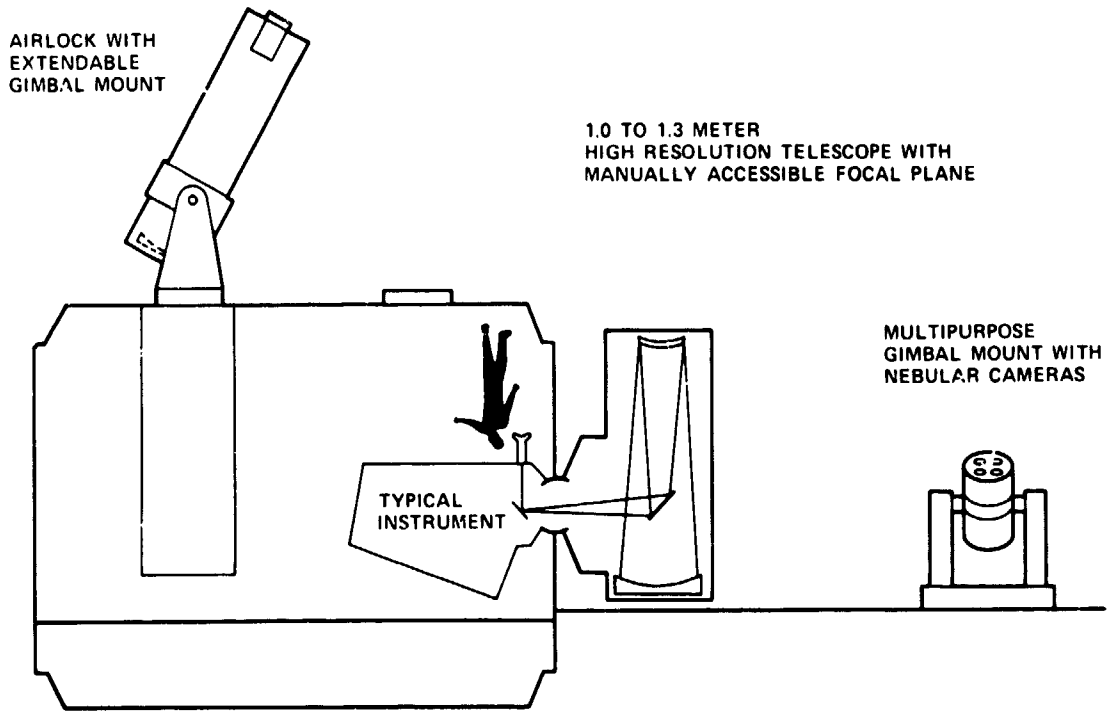

Figure 13-1. Astronomy Lab Configuration

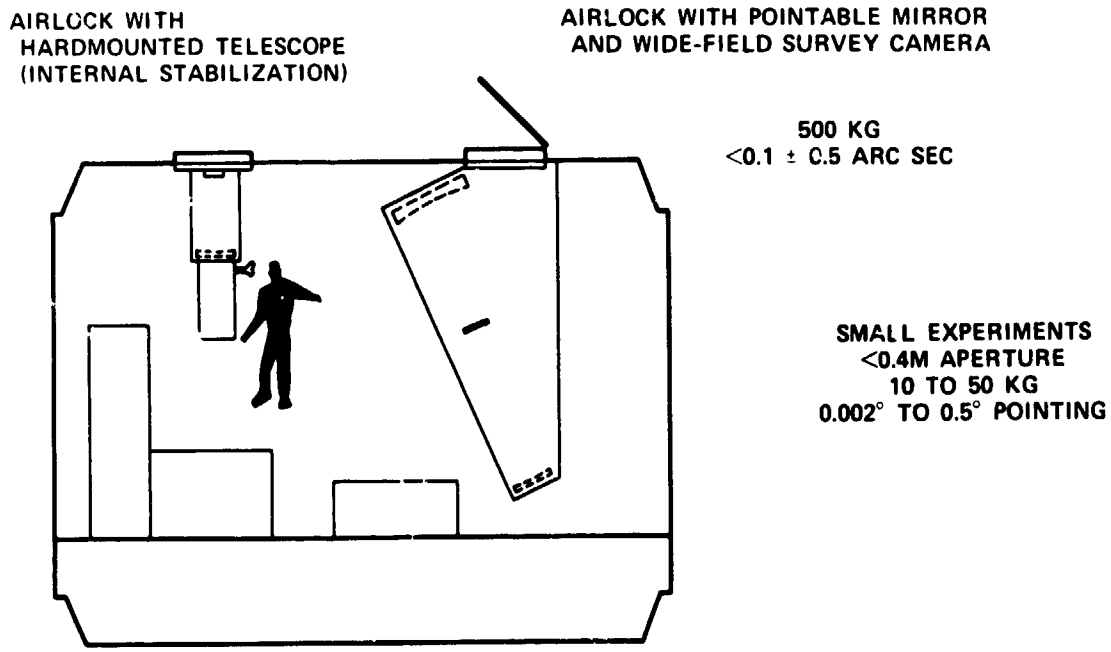

Figure 13-2. Astronomy Lab Configuration

SHUTTLE REQUIREMENTS

The requirements described below have resulted from a consideration of the scientific program objectives and only secondarily of the advertised shuttle capabilities. It is recognized by the working group that a thorough trade-off study is required to optimize the system. In some instances the requirements are fairly flexible and in others not meeting the requirements may either compromise or invalidate the scientific programs. Thus these requirements should open a dialogue between the users and the vehicle designers. A summary of requirements is given in Table 13-1. Only the most significant ones are discussed in detail below.

Table 13-1

Requirements

Missions	
Flights per Year	2-3, dedicated missions
Mission Duration	At least some 30 day missions
Timing	New moon observing
Orbit	Near equatorial with option for anti-sun synchronous
Altitude	250 - 350 n. mi.
Attitude	Inertial, continuous until slew
Orbiter	
Stability	± 0.05°
Pointing Accuracy	± 0.05°
Pointing Knowledge	± 0.01°
Slew Rate	< 10 min., for 90° reorientation, including settling time
No. of Slews	~ 3/orbit, 90° slews

Table 13-1 (Continued)

General	
Data Link	256 Kb/s for 5 min. per orbit, 2 TV pictures/orbit up and down extensive voice coverage (min. requirements)
Cleanliness	Protection for optics, normal clean laboratory environment
Contamination	EMI, effluents and gas, and vibration must be minimized

STABILIZATION, GUIDANCE AND POINTING

Three levels of servo control to obtain the guidance stability required are to be avoided. The shuttle must provide pointing knowledge to better than ±1 arc-minute, pointing to better than ± 0°.05 and stability (jitter) less than ±0°.05.

A minimum usable value for the last two is ± 0°.5. Since this requirement appears to be common to the needs of a number of disciplines, a special effort should be expended to satisfy it. Finally, to be useful for non-solar astronomy, the shuttle must be able to maintain any arbitrary inertial attitude for nearly the entire sortie.

SLEW/REORIENTATION CAPABILITY

One expression of the reorientation requirement is that one should be able to obtain two 15 minute (nominal) exposures during the night side of the orbit. This translates into the requirement of three 90° reorientations about any arbitrary axis per orbit with <u>each</u> performed in 10 minutes or less, including settling time.

NUMBER OF MISSIONS

For efficient observing and to amortize the cost of the facility, three missions per year are desirable. Less than two missions per year reduces the usefulness of the sortie mode to a dangerously low level, precludes the involvement of a substantial community of users (and hence support), and inhibits a response to unusual phenomena. The use of nondedicated payloads, i.e., instruments aboard other discipline's laboratories poses severe interface and scheduling problems. Very long range, careful planning will be required to operate in this mode.

COMMUNICATIONS AND DATA LINKS

To be able to respond to unusual observational results and to involve actively the large number of users expected to participate during each mission, adequate communication must be provided. For maximum efficiency both an up and down picture transmission link is essential. Extensive voice communication via a direct channel is mandatory. A dedicated data relay satellite may be desirable.

CONTAMINATION

Contamination control is essential particularly during the observing sequences. A "zero" level of contamination would be preferred but it is recognized that to achieve this serious trade-offs in other areas might be required. For the purposes of this working group the definition of contamination has been expanded to include all perturbations which might adversely affect the programs/instrumentation. Therefore, vibration and EMI as well as effluents, gases, etc., are specifically included inasmuch as sensor performance and image quality can be seriously degrade in their presence.

POWER AND THERMAL

These areas were not treated in any depth by this working group Thermal control is obviously needed to achieve the high quality imaging described above. Some protection must be provided to safeguard exposed (pallet mounted) instruments during the critical stage of descent. It is evident that the basic telescopes and auxiliary instrumentation power requirements are within that available from the shuttle. However, the electronic instrumentation to service and support the optical instrumentation can be more demanding; the advertised claims for the use of off-the-shelf equipment must be traded off against the extra power and thermal loads such equipment implies.

MAN'S ROLE – EXPERIMENT MANAGEMENT

The major responsibility for the experiment and its success, including construction and use of the instruments, data processing and analysis and finally publication of the results, should reside with the experimenter or experiment team.

Within the sortie lab, man frequently can play a vital role interfacing with the experiments if access at least to the focal plane of the telescopes is provided. This use of man can eliminate the need for highly individual and complicated

automatic systems. Changing film or film cassettes, adjusting and orienting slit mechanisms, changing filters and verifying or fine adjusting telescope pointing are examples of suitable tasks. Additionally the ability to perform minor repairs so that experiments can proceed according to plan can be expected to increase reliability and return. Access to the main telescopes is not mandatory nor is EVA necessary except in emergency situations. The use of mechanical manipulators may be preferred for handling remote experiments such as those mounted on the pallet.

During the mission, man can redirect the instrument configuration and the program on the basis of a near real time evaluation of the data as it is obtained. Adequate communications with the ground must be available so that a larger team of scientists can participate in this evaluation and decision making process as appropriate. The superior accessibility to reference material, the generally more hospitable environment, and the availability of large support computers on the ground as well as the more adequate staffing possible justify maintaining this option. But the inflight team also will require certain support facilities such as process and control computers, data analysis computers and selected reference material to assist them. Detailed pre-planning with special emphasis on integrating multiple on-board experiments will still be required.

In order to interface effectively with a number of experiments all operating nearly 24 hours a day, an expanded crew will be required. The working group recommends that the on-board crew should include two people to pilot the shuttle, a mission specialist who is familiar with the entire laboratory operation, and three "pay load" specialists who represent the experiment teams in flight. These latter are individuals thoroughly familiar with the instrumentation and may, in fact, include the responsible scientists.

A true assessment of man's usefulness, the determination of the optimum modes of utilizing man, and the determination of all adverse aspects (including physiological and psychological programs) should be first obtained by studying carefully the operations aboard Skylab and the C-141. The extent and nature of the involvement with the experiments of a man on board the shuttle will evolve with experience. The working group has not addressed the complicated trade-off situation which exists among weight limitations, crew size and flight duration.

FACILITIES REQUIRED

The Working Group has compiled a representative list of facility type requirements. Some basic needs such as spare parts, working tables, tools, etc., have not been itemized nor is the prepared list complete even in regard to major items. The support facilities required on the ground have not been established

in as complete form, but a ground control facility must be available not only to control the shuttle but also to provide experiment teams a place to process and analyze data being transmitted and the means to interface with the observing programs. Computers, libraries, display consoles, and communication equipment are obviously needed as well, perhaps, as a mockup of the Laboratory and short term living quarters for the experiment teams.

The treatment of the data returned is another aspect of this program. Some might be processed at the experimenters home institution, while others, requiring large, specialized equipment or software might more advantageously be processed in a single laboratory. This concept of a processing and analysis laboratory remains to be developed more fully at a later time.

The following are brief descriptions of the items given in Table 13-2.

Table 13-2

Facilities Required in Sortie Can

- Polaroid type camera.
- General purpose computer and special purpose computers for some experiments.
- Film vault, temperature controlled ($< 40°$ F, preferably $0°$F) for 6 cu. ft. of film.
- Dark room for film changing (dry).
- Tape recorders — for data and for voice.
- Microfiche reader for catalogues, etc.
- Dry nitrogen storage for equipment before use and provisions for recharging and purging.
- One millisecond absolute timing + one part-in 10^{11} frequency standard.
- Test and display electronics.
- General clean laboratory conditions (special clean room conditions not needed).

COMPUTING FACILITIES

Computing facilities within the lab may be of three kinds. A general process computer which would serve to facilitate simultaneous observations with multiple instruments and which could perform real-time coordinate transformation. These would be used for pointing small stabilized platforms or for secondary pointing by larger instruments. Input data for the latter function would come from the orbiter itself. [Direct guiding of the small stabilized platforms by a computer raises problems of digital jitter.] We prefer not to rely on the orbiter computer for such tasks. Manned interrupt and other interfacing capabilities in the operation of the process computer will be necessary. A tape drive or card reader and a control keyboard will be necessary;

A small data analysis computer which will assist the observer in evaluating his data and allow him to make observing decisions nearly in real time; and

Specialized computers required for the operation of individual instruments which will be the responsibility of the instrument designer.

PHOTOGRAPHIC FACILITIES

Dry-processing Polaroid-type cameras, mountable in the focal planes of various instruments, will allow quick look evaluation of field identification, instrument focus, etc.

A dry dark room for film changing will be necessary. It must provide facilities which allow the observer to maintain his orientation while working in the dark at zero g's. Sophisticated film processing techniques (dry) which allow a quick look at some of the actual photographic data should be investigated. In general, however, most high quality photographic data will be processed on the ground.

A cool storage vault for film (exposed and unexposed) will be necessary ($T < 40°F$, preferably $0°F$ for ≥ 6 ft^3 of film).

TAPE RECORDERS

Continuous voice recordings on board will give real time observing records. Time data may be recorded on a side band of the tape. Adequate tape recording facilities for general data storage should be provided, although specialized high data rate equipment will be the responsibility of the principal investigator.

TIMING

Absolute timing accurate to one millisecond and a frequency standard accurate to one part in 10^{11} will be required.

REFERENCE MATERIALS

A color microfiche reader for reference to general astronomical charts and catalogues will be required. However, this cannot replace adequate voice and television communications with support teams on the ground.

EQUIPMENT STORAGE AND MAINTENANCE

A capability for dry nitrogen storage of equipment before use and provisions for recharging and purging must be provided. Some instruments may have to be outgassed prior to launch. Adequate seals and packing for instruments, optical surfaces, etc., must be provided.

General clean laboratory conditions are mandatory, but "clean room" conditions are not needed. Use of toxic materials, glass, etc., to be minimized.

Tools, test and display electronics, and some spare parts will be needed if the observer is to be able to make elementary repairs of equipment. For example, include some black tape for repairing light leaks.

FACILITIES

The facilities necessary in data acquisition include a sensitometer for photographic photometry, secondary calibration sources, and a central refrigeration facility for detectors and the electronographic camera.

USER PARTICIPATION

The general scientific (and perhaps public) community must be informed about the shuttle sortie work at a very early stage and be involved in the planning in an effective way. Only in this manner can we ensure that the shuttle and sortie lab design will satisfy the actual requirements of the users in optical and UV astronomy and that the general astronomical community will be prepared to use the facility when it becomes available. The working group is eager to involve astronomers who have had little past experience in space research, so as to

broaden participation in the program. The involvement of young astronomers, both theoreticians and observers, who will be the users of the facility in the late 1980's or early 1990's is to be encouraged. We believe the average astronomer will be well served if the facility design and mission planning provide for easy access for flights-of-opportunity, simplified interfaces with the sortie lab, and the use of "off-the-shelf" equipment.

An outline of such a plan for involving the general astronomical community in shuttle sortie planning follows:

NEAR TERM

The results of the August 1972 workshop should be summarized in a 1/2 hour presentation to a meeting of the American Astronomical Society (probably at the 139th meeting in January 1973).

A working group for scientific planning should be formed with some or all members chosen by the Council of the AAS. Panels should be established by the working group to take responsibility for planning major instruments or types of observations.

OPERATIONAL PHASE

NASA will assume responsibility for providing the basic observing facility, including major telescopes and general purpose auxiliary instrumentation. Experiment teams will provide specialized small instrumentation or will use NASA-provided equipment to conduct individual observational programs or use existing data in new ways.

SRT/STUDY REQUIREMENTS

It is not too early to begin the development work on some of the basic instrumentation in order to be ready for flights in the early 1980's. All existing study and R&D efforts should be surveyed in other disciplines to eliminate needless duplication. As an example, the Earth Resources program may provide the best inputs to begin new developmental work using photographic recording techniques. Short lead time for development will decrease the cost and increase the effectiveness of specialized instrumentation. These advantages are entirely lost if unnecessary requirements for quality, excessive documentation, or stifling bureaucratic management are imposed.

A preliminary list of areas in which development work is needed follows:

- Ultraviolet filters for specific bandpasses - do materials exist which can be used to provide well defined bandpasses or give a short wavelength pass?

- Large photocathodes/imaging detectors with uniform sensitivity over the entire cathode area; Linear array detectors with high resolution, and high photometric accuracy.

- Reliable electronographic cameras with large format and possibly internal image motion compensation.

- New high resolution, sensitive emulsions for electronography.

- "Small" 3-axis stabilized platforms with remote and internal programmable control.

- Convenient airlock designs to handle instrumentation up to 40-inch diameter.

- Contamination assessment and reduction — For example, a special space experiment might determine the NH_3 cloud characteristics from 4 to 25 lb. hydrazine thrusters. It is suggested that such an experiment be performed on the Apollo-Soyez mission, using a UV spectrometer and/or a good mass spectrometer to monitor cloud dissipation.

- Comparison of the performance, cost, and efficiency of a low to medium resolution scanning or multichannel spectrometer versus an echelle image tube system. High temporal stability and dependability of calibration are important factors as well as speed.

- Polarization devices for the middle UV - maximum throughput and moderate wavelength discrimation are desired.

- Computer concepts for data processing both on board and on the ground. Is a large machine required for near real-time analysis? How does one optimally interface a man and computer in controlling an experiment? The cybernetic design of experiments might prove illuminating. For each basic NASA supplied instrument for the Astronomy program how much automation and digital control is needed or desirable?

- Alternatives to present primary and secondary calibration sources over the wavelength range $1100\,\text{Å} \leq \lambda \leq 3200\,\text{Å}$; the behavior of calibration

standard sources in an orbital environment, should be investigated as impacted by zero g's, wide thermal variations, high vacuum, radiation background, etc. Use of a subsatellite for real-time comparison between a distant (i.e., "collimated") "point" calibration source and stars should be investigated. (e.g., suggested subsatellite configurations, pointing and stability, power requirements, possible sources of calibration inaccuracy, etc.)

- Small off-axis component telescopes for very fast, wide field cameras, etc.

- New generation plate measuring engines with positional accuracies to better than 0.2μ and photometric range $>10^6$ at accuracies of less than 1%.

COMMONALITY WITH OTHER DISCIPLINES

The working group considered only superficially the problem of common needs among the various disciplines. However, a number are nearly self-evident and include:

- Stability and pointing requirements

- On-board process control computer

- Wide band data and communication link

- Telescope mounting

- Photographic processing, storage, and examination

In addition, common observational programs or programs requiring similar instrumentation exist. For example, between disciplines, high speed photometer and spectrometers, and the wide angle cameras described above would be useful in aeronomy for observations of stellar occultation by the earth's limb, airglow measurements, and spectral studies of the geocorona.

The high spatial resolution requirement of UV-optical astronomy is entirely similar to that for planetary astronomy and it can be expected that synoptic observations could be obtained as a routine part of the Laboratory mission during every flight on which the 1.0 - 1.3 m telescope is operating. Further, stellar occultations by planets could be observed when the proper geometry obtains. The surface brightness of the planets may be a much less severe problem for using

common instrumentation than the requirements for carefully controlled light scattering and operation at very small sun angles. These matters require more study.

Cooperation and commonality must exist also with IR and solar astronomy and further joint working groups will help to elucidate these opportunities.

POTENTIAL PROBLEMS AREAS

Some uncertainty and skepticism remained regarding the actual shuttle characteristics. It is presumed that as the needs expressed by the working groups are considered, more definitive specifications of the shuttle performance will be established. Among the potential problem areas which merit early attention are:

- Bridging the gap, in practice, between actual "off-the-shelf" laboratory equipment and that currently used with a requirement for 100% reliability. The degree of automation, ease of community participation, cost, mode of use, and weight are some of the critical considerations which must be traded.

- Overemphasis on the similarity between the airplane programs and the Shuttle Sortie; the more relaxed operational interfaces the airplane program is certainly desirable, but many significant differences exist. These include frequency and duration of flights, scope and size of the instrumentation used. number of experimenters which can be accommodated with individual programs, drastically different enviroments (especially the difference in gravity), preflight training requirements, recovery and response to emergency situations and, last but not least, cost.

- Contamination, Vibration, and Thermal Requirements – It is recognized that a "zero" level of contamination is impossible to achieve but special precautions must alleviate the problems. More importantly, however, there is a concern that certain highly undesirable solutions to thermal, vibration, and in particular, pointing and stabilization problems will be taken merely to minimize the overall project cost and thus pass the burden of design and cost to the users.

- Cost Justification – At an estimated observing cost of in excess of $200,000 per hour, the cost effectiveness of observing with the shuttle compared to other modes becomes questionable. It becomes impossible to justify if other programs and operational modes are jeopardized to support it. Further, as turn around time for the Astronomy Lab becomes longer, the cost effectiveness and indeed overall usefulness decline.

- Operation in a multi-discipline mode -- Unquestionably, some small experiments will benefit from the chance to be mounted quickly and operate frequently by utilizing this mode. The integration of major experiments will be significantly more difficult. Contamination problems, scheduling, stability and pointing, and even weight are important drivers. A simpler interface would be to combine ejected payloads (free-flyers) and sortie laboratories. Common areas among disciplines do exist and have been describe briefly in "Commonality with other Diciplines".

- Easy access to space — In advertising the capabilities afforded by the shuttle, caution must be exercised not to overstate the availability of the shuttle to perform work in a particular discipline. Using a realistic number of flights per year as well as the limited duration per flight, it is clear that only a few observers can be accommodated and, therefore, careful selection processes, AFO's, review panels, etc., will still be required. The observing time which will become available is far greater than can be obtained by rockets, but is still far less than that for free-flyers.

COST EFFECTIVENESS

As per our original instructions, the working group did not explicitly concern itself with costs but did consider how the Shuttle Sortie could be made cost effective. The following points bear directly or indirectly upon this question.

- The use of a 100% reliability criterion is the single most costly driver. For the sortie, multiple experiments to quarantee mission usefulness, the proper use of man for instrument repair (minor), and the abort capability to repeat an experiment may be used to offset and relax this requirement. To a certain extent this argument applies also to free-flyers using a service and re-supply sortie mission to accomplish these functions.

- Reduction of documentation requirements, particularly those serving the sole purpose of diffusing responsibility; traceability is unnecessary

- Standardized astronaut systems

- Concentration on system problems, particularly interfaces rather than on component wear out

- Reduction in the need for redundancy

- Avoidance of highly automated instrumentation — otherwise interface prolems are exaggerated and the advantage of man being present is lost.

- Minimizing the lead time for instrument and/or experiment development — salary cost and overhead are reduced and more adaptability to respond to new technology or scientific discoveries is gained.

- Maintenance of the cost, complexity, and design philosophy of instrumentation as for current rocket borne payloads, i.e., near $\$10^5$

- Reduction of turn around time between sorties

- Simplication of the test procedures — reduce restrictions on component selection or materials used

RECOMMENDATIONS

a. A dedicated Astronomy Sortie Lab is feasible and justifiable. However, more than one sortie per year is needed, three sorties per year are recommended.

b. Quick response to important transient phenomenon must be available via a piggyback operational mode on flights for other disciplines.

c. The sortie lab should exist as one element in a balanced program of astronomical research.

d. As far as possible, the shuttle orbiter should provide those common requirements elucidated by these and future working groups. Characteristic requirements are given in "Commonality with other Disciplines".

e. Further studies should be made to identify common needs and cooperative modes of operation involving the other disciplines.

f. Man must form an integral part of the observing program. Men on board and on the ground must be able to participate actively and in near real time. An on-board crew of 4 is recommended to handle experiments, in addition to the pilot and co-pilot.

g. There must be ready, periodic access to instruments or the focal planes of telescopes. EVA is not precluded but is less efficient.

h. Near real time decision making should be facilitated by proper instrument design and quick-look data availability.

i. Adequate data and voice links (up and down) must be guaranteed to promote f and h above. Ability to transmit two pictures per orbit in each direction as well as direct voice communication are recommended. A 256 Kb/s data transmission link for 5 minutes per orbit is required.

j. Each experiment must be self sufficient in regard to data storage and pre-processing.

k. On-board control computers are needed for regulating experiments and providing necessary scheduling, timing, and coordinate information. Manual interrupt provision is mandatory.

l. Extensive preflight planning should be done with alternative or optional plans included.

m. Earliest possible participation by the scientific community in Sortie planning is recommended. The use of scientific societies and organizations to assist the interface between NASA and the scientific community is recommended.

n. A continuing dissemination of the maximum amount of realistic information regarding the program should be instituted. Talks at scientific meetings are one such vehicle.

o. Major responsibility should be vested in the experimenter and his team. The responsibility for the success of the observations should be primarily his.

p. A simplified set of interface requirements should be established to allow experimenters sufficient information to plan and effect an experiment with a minimum amount of documentation, bureaucratic control, and adherence to formalisms. Safety requirements should be only as stringent as deemed necessary.

q. Trade offs involving contamination, crew size, power, guidance and pointing, etc., should be made only after consultation with representatives of the community of users.

APPENDIX A

NORMAL AND HIGH-TIME RESOLUTION PHOTOMETRY

APPENDIX A

POTENTIAL SORTIE MODE CONTRIBUTIONS

- Rapid response to new discoveries, i.e., pulsars and quasars
- Companion observations to other astronomical observations
- Requires inflight instrument change using same telescope
- Area of potential instrument update, i.e., repeated use with minor modifications
- Use of "night observer" or astronomer can simplify use in small field photometry
- On orbit analysis can vary observing technique or program

SHUTTLE MODE REQUIREMENTS

- Length of Flights — 7 to 30 days.
- Orbit — maximum dark orbit; minimum altitude consistant with guidance.
- Data Requirements — Medium to high; 5μs time resolution desirable.
- Role and Number of Personnel — Experiment system specialist and experimenter and/or night assistant.
- Stabilization and Pointing — Should be better than ± 0.5 arc sec. as small apertures will be required. Offset pointing will be necessary as light from object will be totally accepted by aperture.
- Power and Thermal — Photometer power approximately 8 watts; detector area should be cool, $< 0°C$.
- Combination filter photometer and high resolution instrument, not including telescope, data processing system or control console, should weigh less than 25 kg.
- EVA Requirements — Should not be necessary if airlock operation of telescope instrument compartment is provided. EVA would diminish greatly the value of this mission.

D

- Correlative Measurements – Pointing and stability data should be provided by telescope system.

- General Support Equipment

  a. Visible and UV telescope (Cassigranian) with aperture >1 meter and image quality better than 0.25 arc-second.

  b. Controls and mount to point telescope (offset) to better than ± 0.5 arc-second.

  c. Data Processing, Data Storage and Data Transmission.

  d. Storage space when not in use.

  e. Control console or space for special console.

- Special Operating Constraints

  a. Especially sensitive to contamination.

  b. Dark orbit desirable.

POLICY AND PROCEDURAL CHANGES

If the space shuttle sortie is to be a cheap, reliable, and quick mode of transportation, a vast reduction in documentation, testing and simulation requirements must be effected not only from Skylab or Apollo requirements but from typical observatory class unmanned programs.

ESTIMATED MAGNITUDE OF SORTIE USER COMMUNITY

As photometry would be an auxillary technique to other observations this would probably be smaller than sky survey or spectroscopy user community.

APPENDIX B

HIGH ANGULAR RESOLUTION

ULTRAVIOLET AND VISUAL IMAGING

APPENDIX B

SCIENTIFIC GOALS AND OBJECTIVES FOR THE 1980'S

GENERAL

Spectrally selective (broad and narrow band) imaging, imaging (slit and slitless) spectroscopy, and imaging polarimetry.

SPECIFIC

- Multicolor broad band ultraviolet imaging photometry of star clusters (stellar associations, galactic and globular star clusters, and galaxies) to investigate the stellar population and the evolution of stars in these objects.

- High angular resolution broad band imagery of extended sources (galaxies, diffuse nebulae, planetary nebulae, comets) for morphological studies and to investigate stellar populations and cosmic gas and dust.

- High angular resolution narrow band imagery of extended sources to study the morphology, excitation, element distribution, density, and temperature of atomic and molecular gas in these objects.

- High angular resolution astrometry of binary stars with angular separations less than 1 arc second to increase the number of accurately known stellar masses.

- Astrometry of nearby "moving" star clusters to obtain trigonometric parallaxes free of systematic errors induced by the earth's atmosphere.

- High angular resolution imaging (i.e., slitless) spectroscopy of diffuse nebulae and planetary nebulae to study the morphology, excitation, element distribution, density and temperature of atomic gas in these objects.

- High angular resolution ultraviolet and visual slit spectroscopy of extended objects, (diffuse nebulae, galactic nuclei, compact galaxies) showing small scale morphological, velocity, or stellar population variations across their projected surfaces.

- Broad band high angular resolution ultraviolet and visual imaging polarimetry of extended objects (synchrotron sources and objects containing

interstellar dust – i.e., diffuse nebulae, reflection nebulae, and dusty galaxies) to investigate the nature of the source of the polarized radiation or, in the case of polarization induced by selective extinction or scattering, to investigate the medium causing the polarization.

- Broad band imaging polarimetry of star clusters to investigate the wavelength dependence of polarization in the Milky Way and other galaxies.

- Optical identification and study of unusual objects in confined regions of the sky (e.g., X-ray sources, Quasi-Stellar Objects, galaxies with strong ultraviolet continua, unusual stars).

- Other studies requiring high quality imagery.

IDENTIFICATION OF POTENTIAL CONTRIBUTIONS OF SORTIE MODE OPERATION

The Sortie Mode can make significant contributions in achieving the scientific goals and objectives above outlined. In particular:

- The Sortie Mode allows the use of high spatial resolution detectors (e.g., photographic emulsions, electronographic cameras) whose use in space astronomy up to now has been restricted due to the requirement of either film changing or retrieval. For the type of observing programs which take advantage of the potentially high angular resolution of a space-borne telescope, the use of high spatial resolution detectors allows a significant decrease in f/number (and hence an increase in speed) of the telescope for comparable angular resolution than if currently available lower resolution remotely operated "television readout image tubes" (e.g., Vidicon, SEC Vidicon, SIT Vidicon, Image Orthicon, Image Isocon) are used. In addition, the short duration of flights and the ability to carry massive film storage vaults into orbit will minimize radiation fogging of film.

- The Sortie Mode can make use of man for target acquisition and verification and for conducting operations which are difficult or impossible to automate or conduct remotely (such as orienting a spectrograph slit on the image of and extended object or an object whose position is imperfectly known such as a galactic nucleus).

- The Sortie Mode allows the upgrading of instruments and detectors as technology advances. Hence, hardware design need not be frozen several years prior to flight but can be more in pace with state-of-the-art technology and/or increasing scientific knowledge.

- The Sortie Mode allows the possibility of minor instrument repair or adjustment, instrument deployment, assembly of modularized instruments, and optical alignment and focusing in the environment of space by man.

- The Sortie Mode allows the use and replenishment of expendables (coolants and pressurized gases) which may be necessary for instrument operation and allows the possibility of using high efficiency ultraviolet optical coatings which deteriorate rapidly with time.

PROPOSED FLIGHT SCHEDULE TO MEET THE DISCIPLINE GOALS AND OBJECTIVES

Year	Proposed Number of Flights
1979	1
1980	1
1981	1
1982	2
1983	2
1984	2
1985	2
1986	2
1987	2
1988	2
1989	2
1990	2

MISSION REQUIREMENTS

To conduct significant high angular resolution ultraviolet and visual imagery of astronomical objects on Sortie Mode Space Shuttle flights will require a reflecting telescope of moderate (about 1-meter) aperature with a field of view of about 30 arc-minutes and of optical quality consistent with limitations imposed by the tracking system. Other requirements are listed below.

- Flight Duration – 7 to 30 days.

- Orbit – The orbit is selected to provide best accessibility of observing targets consistent with maximum rejection of scattered and direct light from the sun, earth, and moon and maximum avoidance of the South Atlantic anomaly. A low inclination orbit in the 200 to 400 km range would be desired to minimize the effect of the radiation belts and polar aurora.

- Data Requirements — Digital data rates would be very low if photograph film or electronographic cameras were used as detectors. Access may be required to the orbiter vehicle on board computer or possibly to a small experiment supplied computer to aid in target acquisition. If "television" readout image tubes are used, data rates would be much higher but would remain high for short durations only. An experiment supplied computer and data storage device (magnetic tape) would then be necessary. A two-dimensional data display (CRT) would be desirable, and intermittent two-dimensional communication to and from ground installations may be desirable.

- Role and Number of Personnel in Orbit — To provide adequate rest periods, at least (3) (and preferably (4)), Payload Specialists would be required in addition to the Commander, Pilot, and Mission Specialist. The role of the payload specialist would be similar to that of a ground-based observational astronomer. He would acquire and verify observational targets, operate and maintain the telescope and associated instruments and detectors, document the observations, and make real time scientific decisions as to the quality and usefulness of the data which he is taking.

- Stabilization and Pointing — Stabilization and pointing to 0.1 arc-seconds is highly desirable (0.2 arc-seconds is acceptable) for periods of up to 1/2 hour. Initial pointing of the telescope will require knowledge of the attitude of the orbiter vehicle to within about 1/2 arc-degree. The use of Control-Moment-Gyros (CMGs) is highly recommended to stabilize the orbiter during observations.

- Power and Thermal Requirements — Within presently conceived orbiter vehicle capabilities.

- Weight and Volume Requirements — Within presently conceived orbiter vehicle capabilities.

- EVA Requirements — No EVA will be required for normal experiment operation. It is anticipated that the Payload Specialist will have intermittent access to the instruments and detectors in a shirt sleeve environment for change of film and instrument adjustment.

- Correlative Measurements — Facilities should be on board for calibration of film in orbit and for wavelength calibration of slit spectra.

- General Support Equipment — An accurate clock, possibly a photographic darkroom to check instrument focus and performance, and possibly a small computer with magnetic tape storage capability.

- Documentation Requirements — A tape recorder and log book should be supplied for documentation of observations.

- Special Operating Constraints — It may prove feasible to use the orbiter vehicle as a light shield to allow observations during part of the daytime orbit. If so, the attitude of the orbiter would be constrained during part of orbital daytime. The attitude of the orbiter will be constrained to a lesser degree during all of the nighttime orbit.

- Contamination Requirements — There should be no thruster firings for spacecraft attitude control for a specified period of time before or while observations are being conducted. The use of Control-Moment-Gyros is strongly recommended for orbiter vehicle attitude control during periods of observing.

Quality assurance requirements should be relaxed to allow new instrument and detector technology to be exploited before it becomes obsolete. Furthermore, it is feld that the high cost of conducting space experiments could be reduced if the practice of flying separate instrumentation for various observational projects gave way to the facility concept, in which general purpose instrumentation incorporating interchangeable components could be used to perform a multitude of different observational programs.

It is estimated that a user community of several hundred national and international astronomers presently exists to exploit high angular resolution imagery of the types outlined above.

The needs of the user community could best be met by establishing a National or International Space Astronomy Observatory, which would be similar in concept to Kitt Peak National Observatory and the National Radio Astronomy Observatory.

It is recommended that development of imaging type detectors (film, electronographic cameras, image converters, and television type image tubes) should continue and that their usefulness should be tested (when feasible) on ground-based or balloon-borne telescopes.

APPENDIX C

EXTENDED NEBULAR PHOTOGRAPHY ON SHUTTLE SORTIE MISSION FLIGHTS

APPENDIX C

SCIENTIFIC GOALS AND OBJECTIVES FOR THE 1980'S

GENERAL

The Extended Nebular Photography (ENP) program that is summarized briefly here should be one of the first logical steps in an orderly Astronomy program for the Space Shuttle missions of the 1980's. Several reasons support this view. Because of the wide field for the first ENP missions, and the intent of making a sky survey, these flights should lead to the identification of UV targets for the larger and more sophisticated experiments that are envisioned for the Astronomy program. Because of the relatively low resolution of the ENP instruments, they will require much less in the way of attitude control than the other visible-light and UV experiments. Because instruments of types suitable for ENP, e.g., electronographic Schmidt and Schwarzschild cameras, have already been demonstrated in successful manned and unmanned missions, the development efforts, costs and delivery times for sortie mode ENP experiments should be modest.

Some characteristics of the ENP experiments are summarized in the attached Discipline Working Group Preliminary Report and its Appendices. It is shown there that in addition to survey work, the ENP experiments will answer major scien ific questions, some of which might not even have been asked only a few years ago. Note also that the sortie mode appears to be optimum for ENP. Rockets are inadequate for this task, while free-flying satellites offer more mission duration than required, without provision for replacing degraded components or the simplicity of manned operations. While a lunar-based observatory would offer less geocoronal interference, the problem of data return and that of servicing would be increased and, in any case, such an option is not presently available.

In the early days of ultraviolet stellar astronomy, the possible presence of large UV nebulae attracted considerable attention, but this subject has been relatively neglected since then. On the other hand, thanks in part to groundbased work, the study of low surface brightness, diffuse objects, especially large ones, has attracted renewed and considerable interest. We have recognized the unique nature of the Gum Nebula, an object some 90 degrees in extent, and the existence of hotter and younger versions of it, not detectable in visible light, has been proposed. It has become clear that the standard explanation for the "giant loops" or galactic spurs as supernova remnants must be wrong. The existence of H II regions excited not by stars or even supernova flashes, but rather by low energy cosmic rays, has been predicted, and the claim has been made that there

is diffuse intergalactic matter (on the scale of a fraction of a degree) in the Coma Cluster. These are a few of the recent developments that are relevant to the ENP missions.

The success of the Carruthers camera on the Apollo 16 mission demonstrated the value of wide angle, UV imaging, even at low spatial resolution, 2 arc-minutes. Recent visible-light filter photography by our group (Roosen, Brandt and Ludden, in preparation) shows that comparable resolution in 90-degree pictures of the Gum Nebula is adequate for some astrophysical purposes.

The ENP experiments envisioned here fall into two groups. The first to fly, capable of very wide angle imagery, would involve fields of view as large as 45 degrees (in any case, 20 degrees or more), and rather low spatial resolution of 1-2 arc-minutes. An objective grating (or perhaps a filtering technique) would be used to establish the spectral composition of the radiation. (In making up the list of scientific objectives and considering specific kinds of cameras, I have focussed my own attention on the 1100-1600 Angstrom region, in which important lines such as 1549 C IV, 1488 N IV, and 1239, 1234 N V occur, as well as Lyman alpha, but the other UV wavelengths are also of interest.) The second group of ENP instruments would have a much smaller field — of order a degree — and resolution of a few arc-seconds. These instruments would be used for investigations of selected smaller objects, including targets found in the survey. For this study, I have assumed for each flight that we have a set of 4 cameras, three for different UV wavelengths and one for the visible.

DETAILED

- Low resolution sky survey to locate extended ultraviolet nebulae.
- Modest resolution observations to further elucidate physical properties of selected targets found in the survey.
- Observational test (ultraviolet) of the origin of the Gum Nebula and of the fluorescence theory of supernova light curves.
- Ultraviolet search for hot fossil Stromgren spheres of young galactic supernovae (such as SN 1054 AD, the Crab Nebula supernova).
- Map the very faint visible-light nebulae in the vicinity of giant loops (e.g., the North Polar Spur and Cetus Arc) to determine if they are associated with the loops.

- Ultraviolet search for hot, tenuous H II regions predicted from the cosmic ray heating theory for the interstellar gas.

- Examine old supernova shells for ultraviolet emission from high temperature gas predicted by the blast wave model.

- Visible-light and ultraviolet search to confirm or disprove the claimed presence of diffuse interstellar matter in the Coma Cluster of galaxies. Similar observations to search for "bridges" between neighboring and allegedly neighboring galaxies.

- Other observations, as proposed by the astronomical community after the report of this Workshop is published and the advantages of the sortie mode become known.

IDENTIFICATION OF POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

Most of the above objectives can be achieved in a modest program of sortie mode experiments as outlined below. The degree to which this program can meet the second and last objectives listed above will depend on the number of targets identified in the ultraviolet nebular survey and in future discussions in the astronomical community. However, it can reasonably be assumed that sortie mode experiments can make a significant contribution in each of these areas.

Note especially that these wide angle observations, which can be made simply and rapidly in the sortie mode, will lead to improved definition of objectives, targets and operations plans for more sophisticated observations with the larger telescopes and more powerful analytical techniques (spectroscopy, polarimetry) envisioned for the Astronomy Program in the 1980's.

DESCRIPTIVE TITLES OF SORTIE MISSIONS

- Ultraviolet Nebular Survey (UNS)

- Giant Nebulae Study (GNS)

- Nebular Imagery Mission (NIM)

- Extragalactic Imagery Mission (EGIM)

DESCRIPTIVE TITLES OF SORTIE MISSIONS FOR WHICH REQUIREMENTS ARE OUTLINED HERE

Same as above.

OUTLINE OF PROPOSED TOTAL FLIGHT SCHEDULE OF SORTIE AND NON-SORTIE MISSIONS

- 1979 UNS + GNS (one sortie flight)
- 1980 UNS + GNS (one sortie flight)
  NIM + EGIM (one sortie flight)
- 1981 NIM + EGIM (one sortie flight)
- 1982 NIM + EGIM (one sortie flight)

INSTRUMENT A: WIDE ANGLE NEBULAR CAMERA

REASONS WHY SORTIE MODE PREFERRED

These two missions involve very wide field, low resolution instruments. The field might be as large as 45 degrees. This program is too large to be undertaken with sounding rockets, but too small to require the typical operating lifetime of an Explorer or Observatory-class spacecraft. It is necessary that the instruments be returned to the ground for post-flight calibration and for refurbishment or replacement of contaminated or otherwise degraded components. The film must be returned to the ground for processing and analysis. To keep the instruments simple, cheap and reliable, and to take maximum advantage of (and minimum extrapolation from) proven hardware concepts (e.g., Apollo 16 ultraviolet camera), manned operation of the instruments is preferred, as is the use of film as the data storage medium.

REQUIREMENTS PLACED ON THE SHUTTLE

- Length of flights — Nominal 6-day mission is acceptable.
- Orbit — Nominal 250 n.m. circular orbit is acceptable.
- Data requirements — Return film to ground.

- Personnel in orbit — At least two men, working alternate shifts as experiment operators are needed. On a given shift, the operator will select targets, point the instruments, initiate exposure sequences, remove and replace the instrument shrouds, film, and perhaps optical components (e.g., objective grating, window, coated mirror). He might perform in flight calibration and adjust the focus (see Bellcomm memo B71 11020, Astronomy on the Shuttle Sortie).

- Stabilization and pointing — Nominal pointing accuracy of ±0.5 degree is more than adequate. Jitter must be less than or equal to 30 arc-second excursion from mean position. Drift must be less than 30 arc-second per hour.

- Power and thermal — Assume 4-camera system. Power — 8 watts average, 50 watts maximum. Thermal — constraints not yet determined, but should be less severe than for the larger, higher-resolution telescopes envisioned for the shuttle.

- Weight and volume — 300 pounds, 9 cubic feet (assumes 4-camera system).

- EVA requirements — Depends on location of cameras — EVA possibly needed to interchange outermost optical elements (e.g., objective gratings, windows).

- Correlative measurements — Low frequency ground-based and satellite radio observations with one arc-minute spatial resolution are desired.

- Contamination requirements — There will be constraints (not yet determined) on contamination of optical surfaces and on scattering of light by outgassed or ejected particles.

ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Three flight experiment groups and 10 data-analysis groups, each group consisting of about 3 scientists

INSTRUMENT B: MODERATE ANGLE NEBULAR CAMERA

REASONS WHY SORTIE MODE PREFERRED

These missions involve moderately wide field, modest resolution instruments. The fields would be about 1 degree in diameter. This program is too large to be undertaken with sounding rockets. The instruments must be returned to the ground for post-flight calibration and refurbishment or replacement of contaminated or otherwise degraded components. Also, the film must be returned to the ground for processing and data analysis. The vehicle must be able to accommodate an experiment operator chosen for research as opposed to astronaut-type credentials.

REQUIREMENTS PLACED ON THE SHUTTLE

- See "Shuttle Mode Requirements" for instrument A.
- Stabilization and Pointing — Pointing accuracy ±0.1 degree; jitter less than or equal to 3 arc-seconds excursion from mean position; drift less than 6 arc-seconds per hour.
- See "Power and Thermal" through "EVA Requirements" for instrument A.
- Correlative Measurements — Optical and radio observations to be made at existing ground-based facilities.

ESTIMATED MAGNITUDE OR SORTIE MISSION USER COMMUNITY

Three to six flight experiment groups (perhaps teaming up), 15 data analysis groups, each consisting of about three scientists.

RECOMMENDED APPROACHES FOR INTERFACING WITH USERS (FOR BOTH INSTRUMENTS)

Designate a Field Center for this responsibility; astronomers at the Center to meet with potential users, determine their needs and inform them of the mission capabilities.

FUTURE ACTIONS

Support development of UV filters, especially in the 1200-1600 Angstrom region, and coatings for this region, also development of larger cathodes for UV

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electronography, and of other large cathode, high resolution imaging detectors for UV and visible, also small, wide angle UV cameras, including tilted component telescopes.

APPENDIX D

UV SURVEY CAMERA

APPENDIX D

We assume the spacecraft will be in an orbit with a 90-minute period of which 35 minutes will be in the earth's shadow. It is further assumed that operation of the cameras will be possible only when the spacecraft is in the earth's shadow. This immediately puts restrictions on exposure times. We may expose on one field for the entire 35 minute night or we may make 15 minute exposures on two separate fields. The first alternative permits coverage of only a very limited part of the sky during a 6 day mission (we assume that a 7 day mission will allow 6 days of actual orbital operation) since at sunset we must choose a field at least 140° eastward of the sunset horizon else it will set prior to the end of the exposure (the orbital rate is 4° per minute). Thus a section of sky only 46° wide (40° plus an additional 6° due to the motion of the sun in 6 days) is accessible to observation during a 7-day mission. If we choose to take two 15-minute exposures, then all the sky further than ±60° from the sun is accessible to observation on a given day and a total of 246° will be observable in the course of a 7-day mission. Since with an f/3 camera system, such as we have in mind, sky-limited exposures over a 1000 Å band pass in the average Milky Way field can extend up to 20 to 30 minutes, we are led to the following conclusions:

- The focal ratio should be held at f/3 and pushed to f/2 if possible in order that the full sky-limited potential of the camera can be realized on a single night pass. Even then, the sky limit will not be reached in non-Milky Way fields in a 35-minute exposure.

- To minimize the number of missions required to complete the survey it seems best to limit exposures to 15 minutes. Two missions separated by several months would then make the whole sky accessible.

- The selection of 15 minutes exposures pushes us even more strongly toward an f/2 focal ratio if it can be achieved with a reasonable field diameter. If a 6° x 6° field can be achieved (5° x 5° when overlaps are accounted for) then the band of the galactic equator between latitudes ±10° (7200 square degrees) can be covered by 288 fields. These would require 144 night passes which in turn would require 9 days in orbit if the cameras can operate on every night pass. Thus two missions would make possible coverage of this entire Milky Way band plus a small sample of areas at higher galactic latitudes. At higher galactic latitudes it would seem desirable to utilize the total 35 minutes available for each exposure. In this case the area covered at higher galactic latitudes in the 3 days remaining during a 2-mission program would be 1200 square degrees (48 fields). This would make an acceptable survey but it would be highly desirable to

add a third mission to the program to cover more high latitude area (i.e., more extragalactic objects) and to repeat any Milky Way fields which may have been of poor quality. The entire sky could be covered by 15-minute exposures in the course of 50 days in orbit (9 missions).

At this point, let us examine the character of the camera implied by the above considerations. We wish an f/2 focal ratio with a field 6° on a side (8° on the diagonal). It is doubtful than on f/2 all-reflecting Schmidt will give 1" images over an 8° field diameter but a 2" to 3" image diameter seems a reasonable goal. Further study of the potential image quality vs. field diameter is needed at this point. However, if we assume that a 2" image diameter is attainable, this allows us to set the size of the aperture by matching this angular resolution to the linear resolution of the detector. Assuming the linear resolution to be 20μ then we find the focal length required to make the match to be 2060mm (81.0 inches) and the corresponding aperture is 1030mm (40.5 inches). The total length of the telescope (without folding) will be 13.5 feet and the diameter of the primary mirror (assuming entrance pupil at corrector mirror) will be 56 inches. The plate scale will be 1mm = 100" and the 6° x 6° field will measure 216mm (8.5 inches) on a side. If we assume the total plate holder mechanism to be 9 inches square, then the obscuration ratio is 0.06. If we assume the plate or film mechanism to be a band 9 inches wide all the way across the beam, as would be the case for a roll-film system, then the obscuration ratio will be 0.28, a very acceptable value. This camera will require a stabilization system accurate to ±0.5 arc seconds.

Clearly this will be a major instrument, too large to be mounted within the sortie lab (this would be desirable in order to allow cost reduction through manual operation of the telescope) and probably too large to allow more than one to be flown simultaneously (this would be desirable to allow simultaneous exposures on more than one wavelength band thus reducing the number of missions required to complete a multiband survey). However, this camera represents the ideal survey camera and should be kept in mind in spite of its relatively high cost. I would expect one such instrument to cost on the order of $\$2 \times 10^7$ and three to cost on the order of $\$4 \times 10^7$. If we assume a single camera will require 6 missions to complete surveys in two colors and a spectral survey the total cost (@ a mission cost of $\$1 \times 10^7$ each) would be $\$8 \times 10^7$. The same work could be done on two missions if three cameras were operated simultaneously. In this case the total cost will be $\$6 \times 10^7$. The 25% saving in cost is not sufficient to make the three at a time concept seem worthwhile.

If greater economy were mandatory than I would consider a 20-inch aperture f/3 system. Such a system should be capable of yielding 2" image quality over a 10° x 10° (14° diagonal) field with little difficulty. The economy results from

three factors: (1) the individual cameras are less costly (I'd make a wild guess of $1 x 10^7 for three), (2) they are of such a size that it seems feasible to fly three simultaneously, and (3) with their larger field, they can complete the survey in 1/2 to 1/4 the time required for the 40-inch camera (unfortunately two missions will still be required to obtain full sky coverage at low galactic latitudes but, as a result, a much more adequate high latitude survey can be conducted. Thus a two-mission program using three cameras on each would cost roughly $3 x 10^7$.

The detailed characteristics of such a camera would be as follows:

- Aperture — 20 inches (500mm)
- Focal Ratio — 3
- Focal Length — 60 inches (1500mm)
- Plate Scale — 1mm = 137.5"
- 20μ Image Diameter — 2.75"
- 10° x 10° Field — 10.5 inches on a side
- Obscuration Ratio — 0.38 (assuming 11 x 11 inch plate holder)
- Diameter of Primary — 40 inches

In this case the loss of light caused by running strip film completely across the beam would be prohibitively high and it seems necessary to resort to individual plate holders. Since it is possible that the cameras might be mounted on air locks within the sortie lab (stabilization being provided by motion of the corrector mirror) consideration could be given to manual interchange of plateholders.

The main losses of this system compared with the 40-inch system are (1) a loss of 1.5 magnitudes in the limiting magnitude for a fixed exposure time (the loss is less-about 0.75 magnitude — for a sky-background-limited exposure but this requires an unpermissable increase in exposure time by a factor of two), and (2) a decrease in resolution from 2" to 2.75" since the resolution is now detector limited. These losses are not overwhelming and are somewhat offset by a better coverage of the sky in the course of these missions. It appears that this may be a rather attractive compromise.

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS FOR EACH OF THE POTENTIAL CONTRIBUTIONS OF THIS TYPE SORTIE MISSION GIVEN IN "SCIENTIFIC OBJECTIVES"

- Use of photography highly desirable for survey work
- The limited amount of orbital observing time required does not justify the development of a free-flying satellite.
- The instrument can be simplified and the cost reduced by manned operation.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — Two flights (possibly three), each 7 days long.
- Orbit — Keep β angle near zero to maximize length of night, 250 n.m. altitude.
- Data Requirements — Minimal — only voice communication is required to support contingency situations. All basic data is recorded on film and voice tapes.
- Role and Number of Personnel in Orbit
  a. Six persons (2 shifts of 3 men) to change plateholders and monitor operation.
  b. Two persons (2 one-man shifts) to monitor camera pointing and operation.
- Stabilization and Pointing
  a. All pointing accomplished by shuttle maneuvering.
  b. Most pointing done by platform. Only occasional need to turn shuttle; cameras must be stabilized to ±1 arc-second.
- Power and Thermal — Small.
- Weight and Volume — Three 20-inch f/3 cameras will have a 360 cu. ft. volume and a 3000 to 4000 lbs. mass.

- EVA Requirements

  a. None.

  b. Several times per mission to resupply and recover film.

- Correlative Measurements — Few.

- General Support Equipment — Film storage facility. Time system.

- Documentation Requirements — As few as possible.

- Special Operating Constraints

- Contamination Requirements — It is critical to minimize contamination to avoid fouling the UV optical surfaces. CMG stabilization preferred.

- Other

  a. Assumes cameras mounted internal to Sortie Lab and that plateholders are exchanged manually.

  b. Assumes externally mounted cameras on a pointable platform.

POLICIES AND PROCEDURES WHICH MUST BE CHANGED OR INSTITUTED TO FULLY EXPLOIT THE SHUTTLE SORTIE MODE AND REDUCE THE COST OF RESEARCH IN SPACE

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE OF SORTIE MISSION USER COMMUNITY

Construction and operation of the cameras will concern only a small group of astronomers (approximately 6), but the data will be used by nearly all astronomers as is the data supplied by the Palomar Atlas and the Henry Draper Catalogue.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Prints of original films will be made available to all interested institutions. A special team of astronomers should be assembled to analyze and catalogue the data from the spectral survey.

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES

In the direct-imaging survey there exists one unsolved problem requiring SRT support — the providing of UV filter systems. Two approaches should be explored: (a) thin films of alkali metals, (b) increased size of image tube photo cathodes. The primary problem is to find long-wave cut off filters cutting off at about 1800 - 2000 Å and at 2800 - 3200 Å. To be useful in survey cameras these filters must have areas of about 10 x 10 inches. Peak transmissivity should not be less than 50%.

APPENDIX E

STRATOSCOPE III

APPENDIX E

OUTLINE THE GOALS AND OBJECTIVES FOR THE DISCIPLINE FOR THE DECADE OF THE 1980'S

The need exists for high resolution spectroscopy, photometry and imagery of selected stellar objects from outside the earth's atmosphere. The SS III telescope could be applied to different kinds of astronomical observations of stars, galaxies, nebulae, etc. which are not feasible from the balloon flights.

The SS III telescope is a 1.2m diffraction limited telescope which will be launched in 1976 by balloon. This telescope, or a modified version, will be available for concurrent shuttle flights. The principal mode of data acquisition is a SEC TV system (for balloon flight). Exposures are currently for 2 hours. For orbital consideration, exposures can be longer.

IDENTIFICATION OF THE POTENTIAL CONTRIBUTIONS THE SORTIE MODE CAN MAKE TO SPECIFIC DISCIPLINE GOALS AND OBJECTIVES

- High resolution photometry, imaging and spectroscopy of selected stellar objects such as stars, nebulae, galaxies, etc.
- Spectrum not limited by atmospheric attenuation; also expands visible sky area.
- Utilization of on-board computer of Sortie Lab.
- Longer mission time of Sortie Lab in comparison to SS III balloon flights.
- Possibility of repair during flight.
- Possibility of resident astronomer participation.

DESCRIPTIVE TITLE OF SORTIE MISSION OR MISSIONS REQUIRED FOR EACH OF THE POTENTIAL CONTRIBUTIONS LISTED ABOVE (NOT NECESSARILY ALL DIFFERENT)

- Each Sortie Lab mission meets the requirements above.

DESCRIPTIVE TITLES OF SORTIE MISSIONS FOR WHICH REQUIREMENTS AND CHARACTERISTICS ARE OUTLINED IN ATTACHED APPENDICES

- Research and Applications/High Resolution Astronomy Mission

OUTLINE OF THE PROPOSED TOTAL FLIGHT SCHEDULE OF SORTIE AND NON-SORTIE MISSIONS NEEDED TO MEET THE DISCIPLINE GOALS AND OBJECTIVES

- The number of flights depends upon the success and discoveries of the SS III balloon flights and the number of guest astronomers offered flight opportunities on the proposed SS III/Sortie Lab mission.

REASONS THE SORTIE MODE WOULD BE PREFERRED OVER OTHER METHODS FOR EACH OF THE POTENTIAL CONTRIBUTIONS OF THIS TYPE SORTIE MISSION HAVE BEEN GIVEN

It is anticipated that the TV system of the SS III balloon flights will indicate many selected stellar objects in need of high resolution spectroscopy, imagery, photometry, etc. This type of research will not be possible because of atmospheric attenuation and absorption from earth on balloon flights.

In addition, the longer mission time of Sortie Lab offers the possibility of much longer observing time needed for the integration of signals from very faint objects.

Also, the on-board computing facilities of Sortie Lab offer data processing. In addition, the possibility of the resident astronomer participating in the experiment aboard the shuttle is of great advantage.

REQUIREMENTS THIS TYPE MISSION PLACES ON THE SHUTTLE IF THE POTENTIAL CONTRIBUTIONS ARE TO BE REALIZED

- Length of Flights — Same as Sortie Lab mission.
- Orbit — Typical Sortie Lab orbit.
- Data Requirements — 100 km^2 for 12 seconds at each camera readout; dead period determined by integration time (5m - 2 hrs.); small computer (16 K); routine telemetry and housekeeping (72 K bits) and telescope control commands.

- Role and Number of Personnel in Orbit — 2 persons.

- Stabilization and Pointing — If the electronic guide signal from the SS III telescope can be fed into the Sortie Lab telescope mount, then it is anticipated that the same conditions as on the balloon flight can be accomplished (±0.2 arc-second) Acquisition ±30 arc-second.

- Power and Thermal — 500 watts.

- Weight and Volume — 3500 - 4000 pounds (telescope), 500 pounds (console — 2 racks).

- EVA Requirements — None anticipated unless repair or modification.

- Special Operating Constraints — See "Stabilization and Pointing" above.

- Contamination Requirements — Depends on spectrum to be observed -- General requirements.

BRIEF DESCRIPTION OF ESTIMATED MAGNITUDE SORTIE MISSION USER COMMUNITY

- Depends upon number of applications after AFO 1974.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

- AFO

- Review Board

- Selection

- Flight

- Publication

RECOMMENDATIONS ON FUTURE ACTIONS REQUIRED TO IMPLEMENT THE SORTIE MISSION INCLUDING SRT, STUDIES, AND FUTURE PLANNING ACTIVITIES

- Participation of ground-based program of selected astronomers and facilities.

APPENDIX F

SMALL STABILIZED ASTRONOMY PAYLOADS

APPENDIX F

RATIONALE

There are astronomy problems efficiently attacked using small, stabilized payloads on the Space Shuttle. Two notable examples are:

- Wide field of view UV surveys utilizing photographic film.
- Medium and low resolution spectroscopy.

It is possible in both cases for man to play a significant role in conducting the observing program and to measurably improve the quality of the data and the certainty in obtaining it. These benefits are a result of the way in which the instruments are utilized and of the way the data itself is managed. The utilization of the instruments will be a direct function of the systems design, as will be seen.

SYSTEMS APPROACHES

There are several systems approaches for stabilizing an instrument and/or its field of view. They are as follows:

- Hard mount the instrument in the wall of a passenger compartment (vacuum port of a sortie lab). This approach gives the observer access to the rear of the instrument for viewing of the instrument axis and for handling film, adjusting manual controls, etc. This access is highly desirable; however, an observing program using this approach will be severely compromised if the shuttle itself must do all of the instrument pointing. Therefore, in its simplest form the hard-mounted, vacuum port system is handicapped and can not be considered a satisfactory solution to the observing requirements.
- Hard mount the instrument as suggested above but add a maneuverable external mirror to change the field of view, while again utilizing the shuttle as the stabilized platform. This system approach is that utilized for the S019 experiment (UV Stellar Astronomy) on Skylab. It has the significant advantage over above method of not requiring the shuttle to change attitude in order to have an increased field of view of the sky. For short exposures of film, this approach would provide some survey capability. For long observations the attitude of the shuttle would have to be dictated for longer periods of time, which would probably conflict with the observing program

of the major payload. This approach, because of its limited flexibility, is only a partial solution, but one which should nevertheless be considered for implementation.

- Stabilize the mirror as suggested above. This approach has the advantage of providing a field of view that is independent (within limits) of the motion (maneuvering) of the shuttle. Here again access is provided to the instrument. This approach is a step increase in flexibility over that provided in second paragraph. However, it is restricted because there are limits on the field of view that can be obtained even with a mirror, and while not considered optimum, it should be given consideration.

- Stabilize the entire instrument on an independent platform or gimbal set. This approach has the advantage of making a much larger portion of the sky available to direct viewing by the instrument in addition to reducing the problem of the shuttle attitude. It does suffer the loss of direct access to the instrument unless a way is provided to move the platform into contact with a vacuum port or EVA is used to get to the instrument (to remove film, make unautomated adjustments, etc.). While this system requires an increased use of command, display, and interfaces over that required in first thru third paragraphs, it is going to be characteristic of systems in which the flexibility to perform independent inertial pointing is provided. This system should be thoroughly investigated because of its utility.

- Stabilize the telescope, but bring its image into the sortie lab where it is utilized by the scientific instrument (camera or spectrometer). This system returns the access to the instrumentation that was lost above. Here an advantage gained may be another advantage lost. The effective focal length of the telescope will have to be increased in order to place the image inside the lab. This configuration needs to be investigated together with other approaches to establish a set of trade-offs that can be weighed against the scientific requirements.

All of the above systems will be considered in the MPACT study in the attached systems portion.

APPENDIX G

MEDIUM AND LOW RESOLUTION ASTRONOMICAL SPECTROSCOPY

APPENDIX G

SORTIE MODE PREFERENCE

- Study of a small class of objects either in the exploratory mode or in a "categorization" mode is easily achieved in a short time interval (several days).
- Preliminary, near real time analysis can influence a short observing program.
- Spectrographic equipment is comparatively light (approximately 50 kg) and can be interchanged on telescopes in orbit if the desire arises.
- Special events can be examined on very short notice.
- Observer and "night assistant" can interact easily to accomplish a set of objectives.

REQUIREMENTS ASSESSED AGAINST THE SHUTTLE

- Length of Flights — 7 day basic time period. Infrequent 10 or 14 day flights might be desired for very special cases.
- Orbit — a) Maximum shielding time from the Sun's direct rays; b) Generally 250 to 400 km altitude to minimize absorption and scattering effects of earth atmosphere.
- Data Requirements — Generally modest. With a programmable grating drive, 10 to 1000 bps should be adequate for the spectrometer output. Video tracking of the observed object would require $\geqslant$ 50 kbps.
- Role and Number of Personnel in Orbit — (a) Telescope system specialist; (b) "night assistant"; finds star fields, "guides" telescope to correct position, verifies data quality; (c) Experimenter or his assistant if an interacting observation program appears to be necessary.
- Stabilization and Pointing — The telescope pointing ability to a location will have to be at least ± 1 arc-second and the rms stabilization of about that point should be approximately 1 arc-second. This seems to imply that the shuttle must hold at least $\pm 0.5°$ in inertial space.

- Power and Thermal — Spectrometer power $\simeq$ 25W. On-board computer $\simeq$ 50-75 Watts. The area of the telescope and spectrograph should be free of large thermal transients (10° thermal imbalances) and held to the range 0°C to +40° C if at all possible.

- Weight and Volume — Low resolution spectrometer (10-15 Å): approximately 20 Kg, 0.2 m^3; medium resolution spectrometer (1 Å) approximately 50 Kg, 0.5 m^3.

- EVA Requirements — If airlock exists to change instrument during orbital phase no EVA required. If no airlock available, then either EVA or no instrument changes.

- Correlative Measurements — (a) Data on shuttle inertial position and pointing; (b) video or pictorial starfield data; (c) data on migration of the object in the spectrometer slit; and (d) special simultaneous ground (visible + radio) and space (UV) observation may be performed.

- General Support Equipment — (a) On-board computer for control of wavelength, rate of scan, and quality of measurement. Also the computer will display data in "quick-look" graphical format for diagnostic analyses and should be capable of simple standard analyses in orbit. (b) Electronics hardware will include at least one oscilloscope, some general test equipment, replacement LSI functional electronics for the spectrometers, and extra or special detectors. Calibrated light sources (for flux, and wavelength scales).

- Documentation Requirements — (a) A thorough operations and capability manual should be available for potential users (on ground and in orbit). (b) A limited set of hardware and electronic schematics should be available in orbit for minor repairs. (c) Voice recordings of the observing program on a time calibrated recorder.

- Special Operating Constraints — (a) Shuttle inertial positioning to 1-1/2° for many hours; (b) Minimal g releases by RCS thrusting (implies low thrust levels of approximately 4 pounds or less on the shuttle).

- Contamination Requirements — The telescope optics requirements are more severe and limiting than those imposed by the spectrograph. Spectrograph may be packaged with dry nitrogen prior to launch.

POLICY AND PROCEDURAL CHANGES

- Make Observations Easy for the User Community — (a) If scientist-astronaut (S/A) performs measurements, do not force PI's to attend many planning sessions. Use S/A as the interface to the PI from the shuttle operations management; (b) Impose less paper work. Simple proposals with few copies. Because many observational programs can be accepted for each orbital mission, less stringent review is necessary and more informal communication between PI-S/A-and project management should be possible, and (c) If PI or team member is to take up equipment or make observations, try to impose minimal constraints of training duration, meeting attendance, etc.

- Trade weight for extreme reliability and complexity.

- Learn to accept failures of equipment.

- If weight and/or space is available on other disciplines' flights, try to time-share some experiments.

SIZE OF USER COMMUNITY

Probably several hundred to one thousand astronomers and astro-physicists over a 20-year period; both US and foreign users.

INTERFACES TO THE USER COMMUNITY

Besides the classical AFO technique, which usually has a restricted distribution in practice, if not in theory, general announcements by the appropriate professional societies and scientific journals will help publicize the particular shuttle programs. Interest should be expressed by informal letters with action by the user determining his own involvement. The user participation should be encouraged, fostered, and welcomed but not coerced. Experiment proposals should be informal and judged against the merits of standard shuttle equipment. If the standard equipment is deficient in some important aspect and the user has or could develop the necessary hardware inexpensively, this should be encouraged if the scientific goals are deemed worthy.

FUTURE ACTIVITIES

- Define basic instrument set.

- Ensure that shuttle designs do not impact science requirements.
- Contract for design study on high quality spectrometers which can mate to the shuttle telescopes.
- Examine need for SR&T in spectrometer components or data system.

APPENDIX H

MINUTES OF PRELIMINARY MEETING

APPENDIX H

Participants – N. Roman, S. Sobieski, W. Snoody, R. Melugin (for Q. M. Hansen), Y. Kondo, K. Henize, S Maran, J. Kupperian, A. Lane, D. Leckrone, D. Wasserman (MSFC), W Pratt (Martin Co.), R. Chase (NASA Headquarters).

INTRODUCTION AND OVERVIEW OF CONCURRENT ASTRONOMY PROGRAMS (N. Roman)

The shuttle sortie workshop and related meetings are part of NASA's program to plan for science in the shuttle sortie mode. Problems of concern include determining the interest of the scientific community, determining the relative roles of in-house and outside (e.g., University) participation, etc. The outside scientific community will be invited to become involved after September, 1972. We hope to do our homework in-house in advance of this date and to develop a concrete list of specific questions and recommendations. What is Sortie? The shuttle is:

- A transportation system replacing Thor, Atlas, Titan, etc.
- A base for doing experiments, to be used as a lab over 6 - 7 day intervals.
- A system for revisiting independent payloads for repair or retrieval.

A base for experiments constituted the original sortie definition. However, for the purposes of this workshop the sortie definition has been extended as follows:

- Extend missions from 1 week to 30 days.
- Consider packages delivered and revisited or retrieved within 6 months.

The LST class of missions is still excluded. Nevertheless, for the time being we shall concentrate on 6-day launch-observe-return missions.

The programs indicated are not necessarily approved at this time. For physics/astronomy we are anticipating a continuing series of Explorer class satellites (3 every 2 years or so through the 1980's) with about 1/4 to 1/3 for optical astronomy.

LST for 1979 or 1980 is still in our plans, but '73 or '74 funding constraints may cause difficulties.

Stratoscope III is a 48" aperture telescope launched by balloon, but the study is to include recommendations to make it shuttle-compatible. We won't wait for the shuttle in developing stratoscope III, but it will be a prime candidate for sortie use. By shuttle-compatible we only mean that where possible we shall choose systems that are compatible between balloons and sortie. The optics are designed to be diffraction limited at 5000 Å. The balloon system has a thin window for thermal control which is not useful in the middle UV (removable for the shuttle). It is an all reflecting system which would have to be recoated before sortie use. A major problem is in thermal design — i.e., the shuttle must operate in sunlight, a balloon does not. Stratoscope III has less support than LST, but could do a very valuable preliminary work in preparation for LST. A decision about whether to go ahead with Stratoscope III is due Sept. /Oct. 1972.

It is assumed that it will be supported at its present level for the next 5 years. There is the possibility of replacing rockets with shuttle on a routine basis, either by ejecting off small payloads or using them in the sortie mode. This would allow fast reaction and simple observing over 5 days instead of 5 minutes. Shuttle flights could be scheduled as easily as airplane flights for quick reaction to aurora, etc.

ASTRONOMY SORTIE MISSIONS STUDY (W. Pratt)

Extensive materials related to this talk were distributed to participants. They will not be discussed at length here. (See March 16, 1972 and May 11, 1972 reviews of Martin-Marietta Astronomy Sortie Missions Definition Study.) Miscellaneous points raised during the talk are given below. The purpose of this industry study was to develop a total systems concept from preflight planning to postflight analysis. The Sortie Lab is a pressurized research module linked to a pallet (sortie lab is sometimes called Sortie Can). Should reaction control fuel weight be charged to the shuttle or to the payload? Such special issues should be considered in our final report. The M-M study raises the issue of the need for "toasting maneuvers" to prevent low temperature problems with the epoxy coating used on the shuttle. Such maneuvers could be irreconcilable with the pointing requirements for astronomical observations.

Payloads envisioned by the study always include at least one telescope plus one high-energy array, except for solar payloads. The study assumes no use of multiple small experiments, but the high-energy arrays could be replaced with such instruments.

A total crew of 4 is assumed — 2 experimenters housed in the sortie lab and two shuttle operators. With regard to the question of multiple flights each year there are two discordant views: (1) Program being described to the general community

seems to allow for a flight whenever one wants to go, and (2) it is looking more like we may get only one flight per year for optical astronomy. The optimistic view anticipates 2 or 3 flights per year at most. We should consider both possibilities.

An important topic for later discussion is the need for continuous voice communication between sortie experimenters and ground-based colleagues.

The β angle frequently referred to in the study is the minimum angle between the sun line and the shuttle orbital plane.

Bad logistics problems could be inherent in trying to fly joint solar-stellar missions. However, solar observations and certain stellar observations (e.g., dedicated missions to observe a single object) have problems in common and solar observing techniques might be applied to such stellar missions.

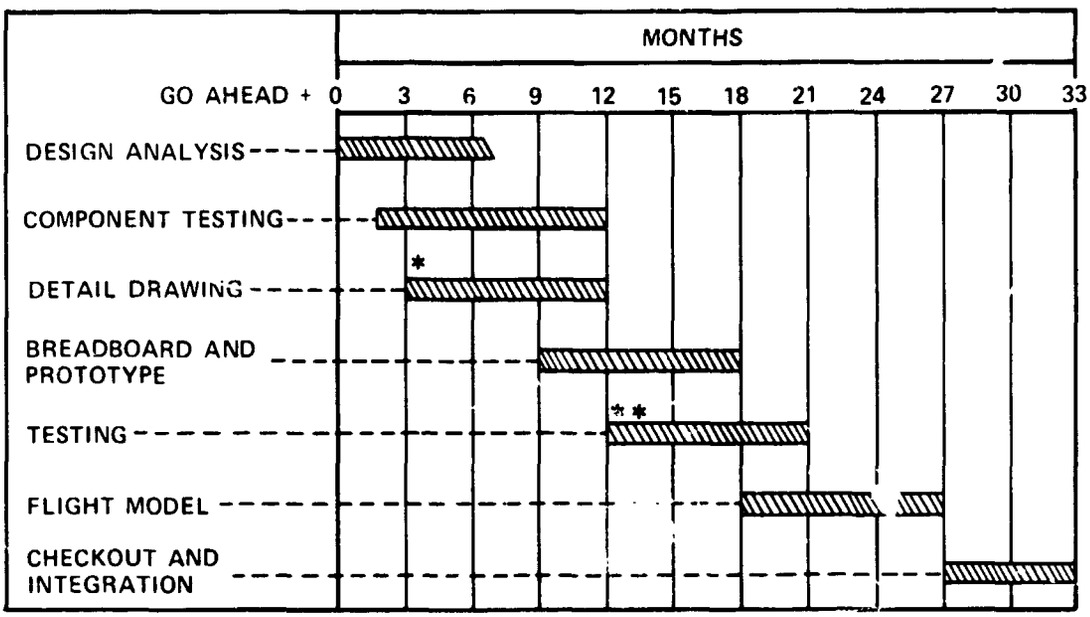
The concept of elliptical orbits to increase observing time in the dark was dropped.

STABILIZED PLATFORM FOR US ASTRONOMY (W. Sroddy)

Such a platform is well illustrated by the ST-100 Platform containing the Carruthers - Tifft - Morton UV package. The platform was designed to carry about 4 telescopes with 2 spectrometers and 2 Schmidt cameras. It incorporated inertial pointing. It was originally planned for Apollo and a prototype was developed. Torque motors coupled to gyros provide the control. All experiments pointed at the same field (e.g., 40° for the UV cameras). It could maintain ±0.01° stability for 15 minutes and this required ±18 arcmin. stability on the main vehicle. It was possible to monitor the jitter. Its dimensions were 5 feet (wide) x 4 feet (high) x 3 feet (deep). Exposure times ranging from 62 sec.-1000 sec. were possible. All data were taken on film to be recovered by EVA. For tentative development schedule for ST100 stellar platform (see Figure 13-H-1).

A very important concept with respect to small, flight of opportunity payloads is that of the Air lock or Vacuum Port. This could accommodate instruments up to 20" aperture. Figure 13-H-2 is a typical configuration.

An important question arises: If airlock instruments are firmly attached, can the shuttle maneuver for coarse pointing? One possible solution would involve the extendable mirror illustrated above, which could be tilted about ±15° and rotated. By maneuvering one internal optical element one might also have a secondary pointing capability. Perhaps the airlock door could contain the mirror



*FINALIZE EXPERIMENT DEFINITION FOR PROTOTYPE PLATFORM.
**EXPERIMENT HARDWARE NEEDED FOR MOUNTING ON PLATFORM.

Figure 13-H-1. ST 100 Stellar Platform

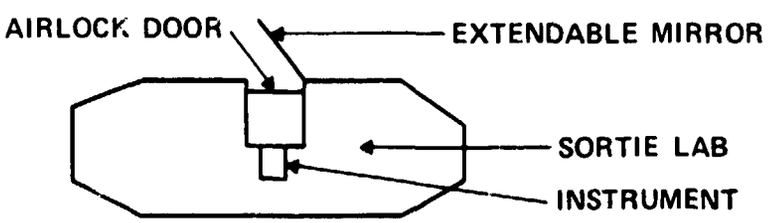


Figure 13-H-2. Sortie Lab Configuration

so that little internal volume would be occupied. The extra reflection could limit observations to wavelengths longer than 1100 Å.

A possible shuttle operational constraint is that the shuttle should get you to within 1° of desired pointing, with secondary capability being used for fine pointing. This could require a great deal of RCS propellant, charged to payload weight. Figure 13-H-3 shows three alternate scientific airlock configurations. Configuration 2 is similar to the Cortez (S-183) and Henize (S-19) experiment for Skylab. Configuration 2 presents the most serious problem of baffling.

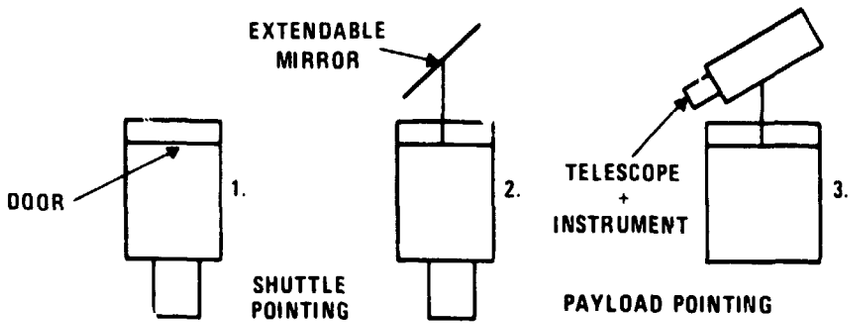


Figure 13-H-3. Three Scientific Airlock Configurations

Flight of Opportunity – Small payloads carried into orbit by the shuttle in addition to the primary payload which justifies the launch but does not require all of the launch capability.

Objective – Provide quick-reaction, fast-turn-around, very-low-cost sortie mission capability in physics and astronomy.

Figure 13-H-4. Space Shuttle Flight of Opportunity and Objective

Payload
- Very low cost scientific instruments and experiment systems
- Simplified, modular construction
- Capability for attached or free-flying missions

Operations
- Minimum constraints on the primary mission
- Minimal tasks for the astronaut or mission specialist
- Simplified integration and checkout
- Similarity to sounding rocket approach

Space Shuttle
- Minimum, standardized interfaces

Figure 13-H-5. Desirable Characteristics for Flights of Opportunity

- Increases opportunity for space observations
- Provides opportunity for launch of quick-reaction, low-cost, rapid turn-around payloads
- Encourages participation of many agency, university, and foreign science groups
- Provides opportunity for unique or problem oriented approaches to scientific investigations
- Provides capability for inter-disciplinary investigations
- Increases utilization of the shuttle
- Bridges shuttle launch intervals using small free-flyers ejected and recovered later

Figure 13-H-6. Benefits from Flights of Opportunity

Experimenter involvement, quick reaction

Modular, low-cost systems

Minimum interfaces, varied automation

Straight-forward application, increased shuttle usage

Figure 13-H-7. Modular Physics and Astronomy Concepts and Techniques

THE AMES CENTER SHUTTLE PLATFORM (R. Melugin for Q. M. Hansen)

This study concerned small payloads for use in physics/astronomy flights of opportunity. (See Figures 13-H-8 thru 13-H-9.)

Who pays for the tracking of small rocket-class payloads thrown overboard? One would need tracking only for rendezvous. The payload could use photographic data storage with the film being recovered. Recovery would take time away from a primary mission. Perhaps one could increase effectiveness of this operation by recovering many satellites in similar orbits. However, orbital

- Identify physics and astronomy needs for flights of opportunity
- Provide modular, low-cost, quick-reaction concepts and techniques for experiment systems to conduct physics and astronomy flights of opportunity
- Exploit proven concepts and techniques used in sounding rocket investigations
- Provide representative concepts
  MSPARS – Modular solar pointing astronomical research system
  MSTARS – Modular stellar tracking astronomical research system
- Identify payload interface requirements affecting the shuttle
- Investigate operational requirements at and away from the launch site
- Establish program requirements for further definition and implementation of modular experiment systems
- Implement interim program

Figure 13-H-8. MPACT Objectives

perturbations make it difficult to maintain many satellites in the same orbit unless they are tethered.

MPACT guidelines provide the experimenter with the opportunity to stay close to his hardware even to the point of going into orbit with it if he wants to. A principal investigator or PI team would be allowed to do this rather than being compelled to do it.

We must keep in mind how we can keep costs low, for example as in the rocket program. Hopefully low cost concepts will come out of MPACT.

The "advertised" program involves taking simple instruments off-shelf. Here failures are not catastrophic because one can simply return an instrument for repair or refurbishment. Costs will go very high if we lose sight of this idea and start requiring 100% reliable, "space-age" hardware of the sort commonly bought for the manned program.

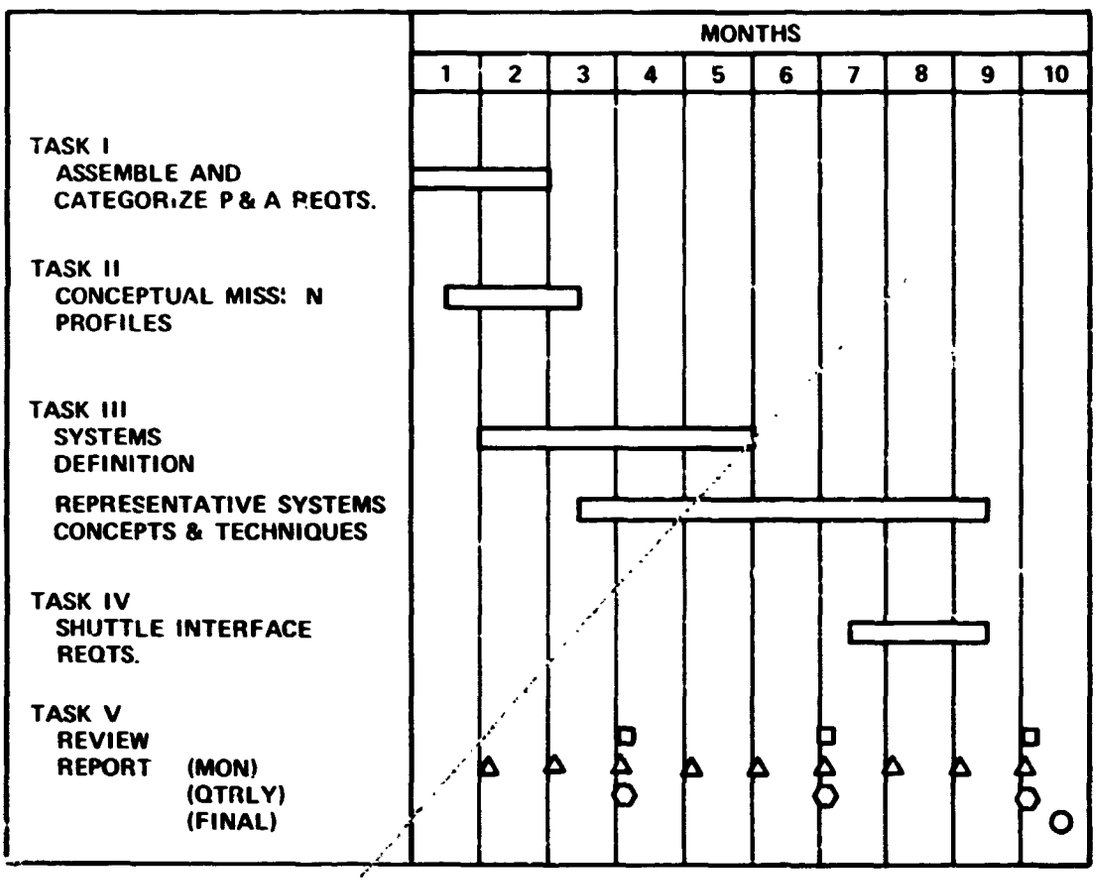


Figure 13-H-9. MPACT Schedule (FY 73)

I hope we can come out of this workshop with a definition of what requirements we place on the shuttle and on the sortie lab, in order that we can fly cheaply. We must define constraints for off-shelf, low-cost equipment.

We should continue to look back at both the manned and unmanned programs and try to avoid their old mistakes.

SMALL ASTRONOMY FACILITY (SAF) (Y. Kondo)

Major points of this talk are summarized in Figures 13-H-10 thru 13-H-13.

Our objective is to meet the basic observing requirements of the astronomical community by providing a high-resolution telescope and a sophisticated pointing facility. This is to be a national facility analogous to Kitt Peak and we are striving for a universality of use. The Phase A study begins July 24, 1972.

- SAF is a multipurpose astronomical facility to operate in the ultraviolet and visible spectral regions which is planned for space shuttle sortie missions.
- SAF is an international facility similar in concept to Kitt Peak National Observatory or National Radio Astronomy Observatory, where opportunities for observations will be made available to national and foreign investigators.

Figure 13-H-10. Small Astronomical Facility (SAF)

The contractor shall perform the following tasks under supervision by and in consultation with MSC astronomers:

- Documentation of and participation in the scientific requirements meeting to be attended by MSC and other NASA scientists to be held in July 1972.
- Preliminary instrument and detector design options.
- Preliminary telescope and tracking system design options.
- Facility configuration options.
- Cost and schedule estimates for hardware.
- Final report to be made 9 months after contract award.

Figure 13-H-11. SAF Phase A Study

The telescope would be of 1/2m - 1m aperture with 4 major modes of observing — imagery, high time resolution photometry, spectrophotometry, polarimetry.

Other specialized instruments could be attached. LST provides high resolution imagery but a small field of view. Our smaller telescope, possibly with 2 alternative f ratios would provide a larger field. The high-time resolution capability might be used for example to observe occultations of stars by planets. The polarimeter could be used to continue work such as that begun by Stecher with his rocket borne polarimeter, for example.

- Flexibility, adaptability and repairability
- Ability to keep pace with the state of art in instrumentation and evolving scientific interest
- Facility for use of photographic and electronographic emulsions
- Economy

Figure 13-H-12. Some Salient Characteristics of SAF

Telescope:
- High resolution diffraction limited 50-100 cm aperture reflector

Modes of Operation:
- Imagery
- High time resolution photometry
- Spectrophotometry
- Polarimetry

Figure 13-H-13. Preliminary Conceptual Description for SAF

The major strengths of this approach include flexibility and adaptability (one doesn't have to finalize a design), a capability of balancing redundancy against the cost of retrieval and repair, and the opportunity to exploit the unique advantages of modern photographic emulsions over an integrating telescope system for wide field ($\simeq 1/2^{\circ}$) observations.

We have to make a strong case for things that can most efficiently be done from the shuttle as opposed to things better suited to ground-based work or to observations from unmanned satellites. I think problems of high resolution spectroscopy of faint objects are better left to LST for example. Of course the spectrophotometry facility is not limited to very high resolution work but would also be suited to intermediate band observations. We are principally interested in providing a versatile and flexibile observing facility here which any observer can use for whatever programs he wishes to carry out.

UV SURVEY FROM THE SHUTTLE (K. Henize)

Question for thought — On the basis of the current cost estimates, is astronomy worth $100,000 per hour?

This program entails survey work at ultraviolet wavelengths, wherein all stars over a large field are imaged and recorded. Two distinct surveys are involved.

- Direct Imaging Survey — analagous to the Palomar sky survey, which would provide crude, broad-band photometric data at two or three ultraviolet wavelengths (e.g., 1800 Å, 1300 Å), also provides a record of time variable events at the epoch of observation.

- Objective Prism Survey — a UV analogy to the HD catalogue or the southern Hα survey, which would allow us to detect unexpected astrophysical phenomena.

Such survey work is necessary as a basic preliminary to LST. It would provide a great deal of medium-resolution data for studies of stellar atmospheres, etc. The survey could be accomplished with an Epstein Schmidt telescope where the refracting correction plate of an ordinary Schmidt camera is replaced with a mirror. This results in only a slight and not very significant increase in aberration.

What total exposure time is required for a significant survey? 410 fields are required to cover the sky, at 10 minutes per exposure. With 3,000 observing minutes/mission it would take two missions to survey the sky in one color. To do multicolor work we could fly more missions or fly more cameras per mission.

How about using an image intensifier to provide a long wavelength cut-off and to decrease exposure time? Give me 6 inch photocathode and we have the problem licked.

We are basically out to do UV classification work and to look for the unusual. We will be doing a "survey" from skylab with 3 Å resolution down to 1350 Å but we will only have time to cover 1/3 of the milky way.

One should anticipate the question: Why use the shuttle for this job rather than a dedicated satellite with a large field and low resolution?

One should use photography for the survey. Hence, the shuttle is best. Also the total observing time required doesn't justify a unique satellite. The cost can be kept very low if the instrument is man-operated. An important consideration is whether we should plan to give man manual access to the sortie equipment.

SCIENCE AND THE SHUTTLE (S. Sobieski)

I am reporting preliminary results of a survey of Goddard astronomers which resulted in a work plan regarding the kinds of science one might do with the shuttle. We have not been concerned about instrument design and whether some of our suggestions are feasible is open.

SHUTTLE ADVANTAGES

- Liberal payload weight and size constraints.
- Potential for changing observing modes quickly, based on quick-look results.
- Capability for pre-flight, post-flight and in situ calibration.
- Versatility and flexibility in experiment design and operation.
- Immense data storage capability via photography/electronography as well as capability for wide dynamic range. About 10^{13} bits of data per exposure would be typical.
- Immediate availability of data, including target acquisition in real time.
- May be the only way to get some science done in the absence of other vehicles (a dubious advantage).

SCIENCE AND MISSION MIXES

- Flights of Opportunity — a strict "as space is available" mode. There are difficult problems of compatibility here. For example, how compatible would astronomical payloads be with earth resources payloads where the shuttle bay must be open toward the earth?

  Such flights of opportunity could be planned on a short term basis. They would not be the primary mission objective but at least they would be scheduled in advance.

- Objective Oriented Missions — Such missions could be dedicated to doing a single kind of observing — e.g., use of a very large grazing incidence spectrograph. Or they could involve a facility, with a mix of instrumentation. They could include very long-term programs.

- Support of Free Flyers — For example instrument testing, calibration work, etc. in support of HEAO or LST.

- Resupply of Observatories — These are shuttle missions but strictly speaking not sortie missions.

I count on certain other facilities to provide background for the shuttle. We should not duplicate the tasks of OAO-C or IUE. LST will provide high quality imagery and high spectral resolution. Rocket programs will continue. The shuttle should not be used in competition with these facilities.

WHAT CAN THE SHUTTLE DO?

- The UV survey of Henize, both spectral and broad-band, although the spectral survey might require too much observing time.

- Polarimetry — requires difficult special instrumentation; polarimetry of close binaries, selected OB association stars; selected field stars; wavelength dependent polarimetry.

- Monochromatic photometry of extended sources, including comets, open clusters, giant loops, intergalactic bridges, emission nebulae filaments.

  Aren't you light-limited on such objects? Would this not duplicate LST work? Moreover, can you really design the necessary 0.1 sec resolution into a 2° field instrument?

- EUV observations which would entail searching a small number of stars for coronal lines, etc., with a grazing incidence system. So few targets are involved that this work could be done practically only on the shuttle.

- Astrometry taking advantage of the high image quality potentially available outside the atmosphere. Possible programs include measuring the trigonometric parallax of the Hyades, determining proper motions of special groups of stars (e.g. WR stars), searching for planetary systems, etc.

  To improve the measurement of the Hyades parallax by an order of magnitude you're going to need an accuracy of 0.001 arcseconds not only for the Hyades but for the background reference stars you're using. You'll not be able to get that kind of accuracy from a wide-field instrument and with an instrument with a sufficiently small field and large plate scale you probably won't be able to find suitable background stars. I don't believe you can design 0.1 sec resolution into a 2° field instrument.

I think you might find some individual Hyades stars with suitable reference stars sufficiently close by. The usual problem in such work is that of emulsion slippage.

- Absolute spectrophotometry involving pre- and post-flight calibrations or in-situ calibrations by use of a calibration source carried by a subsatellite. Our task would be to establish a well-calibrated system of secondary stellar standards, both bright and moderately faint, for use by LST and other spacecraft.

- Low-light level spectrophotometry, primarily of faint extra-galactic sources, X-ray sources, etc. and primarily in the absence of LST. Use of the shuttle as a test pad for other instruments and for calibration work may be important and should be included.

COST EFFECTIVENESS AND SHUTTLE SCIENCE (J. Kupperian)

UNIQUE SHUTTLE FEATURES

The shuttle is a transportation system plus a cabin containing men. It is characterized by a short orbital life. It provides round-trip capability, high reliability based on frequency of use, abort capability (you have a second change if your experiment fails the first time; you have up to a week before you must commit your experiment to use), and manned capability.

SOURCES OF COST SAVINGS

Most spacecraft money is spent in a "goldfish bowl syndrome" wherein we are constantly watched by management (and the public) which cannot tolerate a failure. Product reliability of 85-95% is common even on production line items. But assuring 100% reliability becomes very expensive. Cost savings with the shuttle derive primarily from the capability to update and refurbish instruments, thus extending their useful life, and in the capability for payload recovery and reuse.

Sortie missions of 7 days are not cost effective for "production" modes of work. Since we're talking about a total expenditure of about 3.8×10^8 dollars/year, the shuttle would not be cost effective as a means of transport alone.

ADVANTAGES OF THE SORTIE MODE

Sortie observations allow one to use expendables and returnables. For example, film is unsuitable for use in unmanned spacecraft. You couldn't carry enough of it and it would be ruined after a period of time. Also cryogenics could not be flown in unmanned missions but could very reasonably be used in a 7 day sortie mission.

The shuttle sortie is the best observing mode for short lifetime experiments. You simply can't design an unmanned satellite to last for, say, exactly 30 days. Instrument testing and program evaluation leading to future missions is also an important capability.

MANAGEMENT

Large cost savings would come from a simplified interface. For example, a computer that does all things for all observers could be very expensive. Much more could be saved by having a man do certain tasks rather than automating them via some standard interfacing system. Extensive paperwork and documentation is very expensive and would be of little use in such a program. The usefulness of traceability should be questioned for the sortie mode. Costs could be minimized by minimizing astronaut preference items and by standardizing astronaut systems. The shuttle cannot avoid systems failures. One should concentrate on such systems problems rather than on equipment wear-out problems. If a system fails, the mission will end before 7 days anyway.

In the past NASA has overdone redundancy. One should strive for system redundancy if he can get it, or mission redundancy if he can't. He should go after redundancy only after the total system is built and proven. In thinking about experiment automation vs. manual control, we should consider if we want over-rides from the ground. If we are to commit to manual controls, we should do so wholeheartedly. Shuttle costs will be very large unless we can get very rapid turnaround time (Figure 13-H-14). We've got to make it easy to get on the shuttle to make it profitable. We cannot cost it out of existence with paperwork, etc.

THE MARINER EXPERIENCE (A. Lane)

Mariner stellar spectra were acquired through an accident in that we found a 2 hour period when no other kind of observing could be done. A great deal of management rigidity had to be overcome before we were allowed to do the observations.

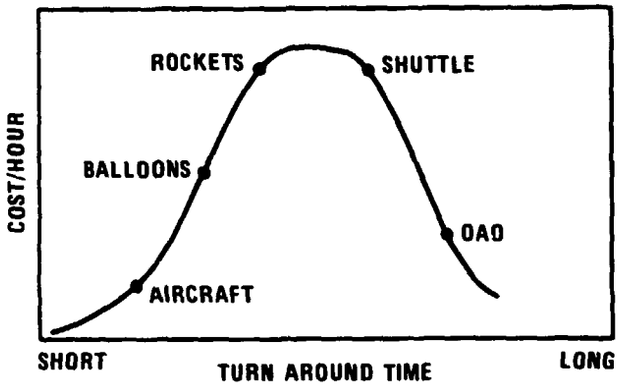


Figure 13-H-14. Shuttle Cost

All software coding was rigidly locked in 6 months before launch and could not be changed. We could not change analysis/observing techniques to cope with the Martian dust storms. We must have great flexibility in the sortie; we must allow the observer to make real-time choices about the modes of observing. For example, by use of small computers on board, he could quickly compare what he is observing with what he expected to observe to decide if it is worth continuing that mode of observation.

Astronomers need real-time decision ability. In advance planning of observing sequences one should allow for time to re-observe or to do new kinds of observation.

Probably one should plan 8 days of observing for a 6-7 day mission with alternatives built in. One needs a measure of data pre-processing on board to allow evaluation of the quality of observations. That would be difficult with photographic data, unless we had a darkroom in the shuttle.

At some state we should address ourselves to problems of data management and to the problem of legal ownership of the data after flight.

Problems raised by manual access to the instrumentation, based on the IR payload study were reviewed.

Payloads incorporating manual access to instruments on the pallet generally require primary pointing by the shuttle itself. This introduces possible problems of weight (for sufficient thruster propellant or for CMG's), contamination and maneuver scheduling. IR configurations with manual access had lower projected operating efficiencies (about 32%) than did configurations without such access (about 70%).

One CMG is required for each 6°/min slew rate. Each CMG is about one meter in diameter and weighs 500 lbs. On the other hand to provide 1°/min slewing about Y or Z axes or 6°/min about X axis, one needs 25 lbs of RCS propellant. Thruster exhaust is a source of contamination. A small vernier system might use only 10 lbs. of propellant per day, but it also is a source of contamination. About 150 watts of power is required to run CMG's.

Manual access to instruments requires a long f-ratio system and hence a small field. A tertiary mirror is required to bring the light path into the lab. Putting the telescope into the sortie lab to avoid use of the tertiary mirror apparently doesn't solve the problem. A Pfund type telescope as proposed for the solar payload obviates some of these problems. To guide the whole shuttle clearly presents contamination, weight and scheduling problems. This will be true for earth observations as well as for astronomy.

However, to do astronomical work we want the capability to hold an inertial attitude for the whole mission.

To hold an inertial attitude of ±1/2° for a 7 day mission with hydrazine thrusters requires 25,000 pounds of propellant charged to payload weight. The M-M study recommends CMG's instead and for the IR payload it recommends a configuration without manual access.

DISCUSSION SESSIONS (July 19, 1972)

SORTIE MISSIONS AND ASTRONOMY IN THE 80'S:

UV Photographic Sky Survey

Direct imaging and classification spectroscopy. Because of the relatively short duration of the program and the necessity of using photographic materials, this program is particularly well suited to the shuttle. It will provide a complete UV record of the sky at a given epoch, provide data for UV classification work and allow one to search for unexpected astrophysical phenomena.

A possible source of competition is an NRL explorer-class electronographic survey satellite proposed by Carruthers, which it is claimed would cost less than 10^7 dollars. There are problems with this proposal, however, which will not be discussed further here.

Calibration of Stellar Fluxes (1100 Å to 10,000 Å)

Although calibration problems can also be attacked with rockets, the shuttle provides an opportunity for in situ comparison between stars and a collimated point source carried in a subsatellite, as observed by the same instrument. In this way problems of calibration transfer through an atmosphere or in the complex environment of a ground-based vacuum tank might be averted. Moreover, the shuttle would allow one to establish a system of secondary comparison standard stars, both bright and faint, suitably scattered around the sky — a program that could be carried out only with great difficulty with rockets.

High Time Resolution Photometry

High time resolution UV photometry of pulsars may give one a basis for choosing between pulsar models in situations where X-ray and radio data are inconsistent. Time resolved spectrophotometry of stars before and during occultation by the earth could provide an important commonality between astronomy and aeronomy payloads. Time monitoring of L_α from stellar sources could provide an interesting means of detecting chromospheric activity. Time resolved UV photometry of close binary systems would also be of interest. Observations of β Lyr, Pleione, etc. would be worthwhile.

With the exception of the pulsar observations and the occultation programs, most programs would require time resolution of approximately 10 sec rather than of the order of milliseconds. Such observations are probably no more time consuming than are other kinds of programs.

Such observations might require special recording equipment (although data rates probably would not be exceptional), and would definitely require an on-board, quick-look data processing and evaluation capability. The observer should be able to alter or terminate such time resolved observations, based on an initial evaluation of the data.

Studies of the Interstellar Dust

Ultraviolet polarimetry as a tool for the study of interstellar gain properties could be carried out with greater accuracy with the larger aperture instruments available on shuttle sortie missions than has been possible with rocket-class instruments of the sort flown by Stecher.

The variability of the UV interstellar extinction function around the sky has been and will in the future be reasonably well established by other satellites. However, shuttle sortie instrumentation would be ideally suited to such programs as the point by point mapping of extinction in stellar clusters and associations for example.

Astrometry

The high image quality potentially available with superior optical systems flown above the atmosphere may allow a significant improvement in the measurement of stellar parallaxes and proper motions, in the resolution of close visual binaries, in the resolution of central regions of globular clusters, etc. It would be highly desirable to allocate many such tasks to a single instrument — e.g., a single moderately wide-field, high speed camera for both astrometry, cluster photometry, etc. However, it is questionable that adequate spatial resolution could be gained from a wide-field camera. Ground-based parallax and visual binary work is commonly done with f/15 to f/20 systems with large scales and small fields of view. Exposure times would be minimized in an electronographic system, but such a system could not significantly degrade the spatial resolution.

Stellar Interferometry (diameter measurements)

Two systems have been suggested: (1) a knife edge experiment where one observes the diffraction of starlight as a star is occulted by a sharp edge, and (2) measurements with a Michelson interferometer where the atmospheric scintillation problem is negated by flying the instrument in the shuttle, as proposed by Currie of the University of Maryland. Stability of the knife edge would have to be maintained to within a few arcseconds. The edge must be sufficiently long to fill the aperture of the detector.

Stellar Observations of Extreme Ultraviolet Wavelengths (XUV)

These observations entail use of a grazing incidence spectrograph with moderately high (we believe) spectral resolution. The observing would be best suited for flight of opportunity status since it is not clear that any XUV radiation will be detectable from sources outside the solar system. It is not entirely clear that the experiment is suited for 7 day sortie missions, as it may be light limited and the focal length involved may be too long. Such observations may also be proposed by the high energy astrophysics group.

Nebular Detection

The absence of airglow, atmospheric scattering, etc., at sufficiently high altitude will facilitate the detection of faint nebular sources. A very fast (e.g. f/0.5) wide field camera will be required.

UV Nebular Photometry

Photometry of nebulae in selected UV bandpasses at high spatial resolution may be facilitated with a fast, wide-field, high resolution camera of the sort suggested for other programs here.

Eclipsing Binary Studies

Although such observations are very time consuming they may be justified for particularly interesting systems. They are probably best suited for "target of opportunity" work when other experiments on board do not have priority.

UV Studies of Stellar Chromospheres

Very high spectral resolution observations over a very limited range in wavelengths are required here. Although such work might be performed with IUE-class instruments or with OAO-C, it could also be carried out with reasonable efficiency from the sortie — i.e. integration times of about 2 hours might be required over a bandwidth of a few A. One might consider use of a Fabry-Perot system for extremely high resolution observations on individual spectral features particularly molecular bands in the far UV.

Studies of the Intergalactic Medium

Observations of intergalactic bridges, etc., involve methods similar to those applicable to nebular detection and photometry discussed above. Spectroscopic problems relevant to the intergalactic medium are more appropriate for LST-class instruments.

Spectroscopy of Close Binaries

Of particular interest here are classification spectra of the components of close visual binary systems. The high spatial resolution potentially offered by sortie instruments may allow one to obtain separate spectra of such systems. Systems whose components differ greatly from each other in luminosity are of the greatest concern. Observing problems one may encounter include those of fine guiding on such objects, minimizing scattered light, etc. Similar problems of high spatial and high spectral resolution spectroscopy will doubtless also apply to planetary studies and we may share these in common with the planetary group.

High Time Resolution Stellar UV Spectroscopy

Here we are considering entire spectra from 1100 Å - 3000 Å with 10% photometric precision taken with a time resolution of about 10 sec. A single flight of opportunity would be sufficient to test the desirability of continued work in this area. Presumably chromospheric activity, stellar flares, variable emission in B type stars, etc., might be monitored in this way. To some extent such work might be done by OAO-C and IUE but at somewhat coarser time resolution.

In addition to the programs listed above, the following programs were discussed but were given less emphasis with respect to shuttle sortie observing modes:

Flux Distributions of Extragalactic Sources

Intermediate-band and high spectral resolution spectrophotometry of quasars, distant galaxies, etc. should be a principal objective of the LST. Those objects which are sufficiently bright as to be accessible with sortie-class instruments (e.g. 3C-273) may be adequately observed with instruments designed for the programs listed above. We shall not plan for the eventuality that LST will slip badly in its scheduling, because it is likely that the shuttle will also slip. As a point of philosophy we would do well to emphasize the kinds of experimenting for the shuttle that the shuttle is best able to do.

Spectrophotometry of X-ray Sources

Similar remarks apply as those given under "Flux Distributions of Extragalactic Sources" above for faint extragalactic sources.

High Resolution UV Stellar Spectroscopy

Such observations are best left to other satellites such as IUE and OAO-C. The following facility instruments were suggested as being appropriate to the programs listed above and to others not as yet discussed:

- A photographic UV survey telescope (e.g. Epstein Schmidt), for direct imaging and classification spectroscopy.
- A high spatial resolution camera for photography/electronography (with field and f ratio to be specified later).
- A photometer for both normal (UV-visible) work and for high time-resolution observations.
- A nebular camera (very high speed, wide field).
- Stratoscope III or a similar telescope affording high image quality.
- A grazing incidence spectrograph (1/5000 resolution).
- A low to medium resolution spectrometer.
- A small, stabilized platform for mounting specialized instruments.

In considering these instruments we must be certain that they are compatible with shuttle and pallet characteristics.

IDENTIFICATION OF SPECIFIC ADVANTAGES AND UNIQUE CAPABILITIES OF THE SHUTTLE

The following list is based upon the 18 July presentations of Sobieski and Kupperian and the general discussions of 19 July:

- Provides an environment of flexibility where quick decisions can be made and observing procedures modified or improvised as previous observations warrant (This advantage might not be realized if man does not have manual access to equipment or the facilities for quick data evaluation).

- Allows quick response to events of scientific importance — supernovae, comets, etc. — and the planning, fabrication and use of small, specialized experiments on a short time scale (These advantages will be minimized if we are allowed only one flight per year for optical astronomy).

- Allows flexibility in instrument design and use — Instruments may be recovered, modified or repaired and reflown at low cost. One doesn't need to rebuild an entire payload when a small part of that payload fails or becomes obsolete. Minor on-site repairs are feasible.

- Allows minimization of payload cost by use of "off-the-shelf" equipment. (This advantage may be lost if man has no access to the equipment and if it thus must be automated in its functions). Such equipment facilitates experiment design by university groups, etc.

- Allows the use of expendables and returnables such as photographic film. (Film can be maintained in a "lead vault" for many months, although possible problems with exposure of electronographic film to particle background must be explored). The practicality of "lead vault" storage and subsequent transfer of film to cameras, etc., rests upon the premise of manual access to the observing instruments. Film provides an immense data-storage capability.

- Allows the use of cryogenics for cooling detectors, etc. — an advantage afforded by no other kind of satellite.

- Provides a platform for in situ testing and calibration of equipment and for testing out observing procedures and programs for LST and other

satellites. (We must weigh such an advantage against the time it might take away from primary experiments, considering that much testing can be done on the ground.)

- Provides liberal constraints on payload weight and size — Cost of miniaturization reduced, large scale experiments become feasible, etc.

- Provides a highly reliable facility, based on frequency of use.

- Provides a low cost platform for short lifetime experiments.

EARLY AND LONG TERM PLANS

- Do we wish to plan for a major astronomical facility on early flights or do we adopt a slower evolutionary approach (start with simple testing, proceed to full observing; start with simple pallets, proceed to complex ones; start with 7 day mission, proceed to 30 day missions)?

  Such an approach can be criticized as being wasteful. One can take the complete set of instrumentation along on a flight and assume it will work. There is a 50-50 chance that it will but if it does not it can be returned for repair. With the possibility of only a few flights per year, none should be wasted simply in proving out payloads.

  The working group does not want an evolutionary approach. We should plan on immediate use of the full facility. Clearly we will need some phasing, as we won't be able to do every observation during the first year.

- Do we wish to emphasize dedicated optical astronomy missions or more limited missions incorporating space and time-sharing with other facilities?

  Two kinds of sharing are possible: sharing with other sortie facilities or sharing space and time on satellite placement flights (note that LST and HEAO leave little space for other payloads and other satellites may go to inappropriate orbits).

  If we are not prepared to fly dedicated missions we may be in the position of not being able to get space on other flight or have very low priority vis-a-vis operational requirements. We face a continuous problem of incompatability with other payloads, etc. This could prove to be a very inefficient means of getting astronomy done with the shuttle. It would clearly be preferable to incorporate both dedicated facilities and "piggy-back" payloads into our planning.

We are willing to share flight space and time but we anticipate great interfacing problems and the cost effectiveness of the mission may go down.

We anticipate greatest commonality with planetary studies and with aeronomy. We recommend a common light gathering capability with planetary astronomy. Synoptic planetary studies, requiring only a few photographs during each mission over many years, using equipment common to stellar and planetary astronomy, could easily be carried out. High time resolution spectrophotometric observations of occultations of stars by the earth's atmosphere would provide data of great value to both astronomy and aeronomy.

MISSION REQUIREMENTS (POINTING AND GUIDANCE, POWER, THERMAL CONTROL, ETC.)

As is discussed below under "the role of man," the working group strongly feels that experimenters in the sortie lab must have relatively easy (hopefully excluding EVA), periodic access to astronomical instruments. Otherwise much value of the shuttle is lost. On the basis of the Martin-Marietta study this implies the necessity of inertial stability (to about $\pm 1/2°$) of the shuttle for the entire 7 day mission. This will require good, low-thrust mode stabilization.

To minimize film contamination, the saturation of detectors, etc. by particle radiation (the south Atlantic anomaly for example) astronomy payloads may have to be flown at relatively low altitudes.

Further discussion of mission requirements will be included in the discussions of individual instruments by participants to whom those discussions were assigned.

Discussion of shuttle inertial attitude pointing modes and requirements. (See reports on NAS8-28144.)

There are 3 alternate ways of maintaining X-POP attitude (longitudinal axis perpendicular to orbital plane) for 7 days:

- ACPS — attitude control propulsion system.
- RCS — reaction control system.
- CMG — control-moment gyro.

ACPS requires 25,000 lbs. propellant for 7 days. This could be reduced to 6,000 lbs. by use of a single thruster (results in small orbital perturbation). RCS is a cold gas system with small thrusters. It is only 1/3 the weight of the CMG system required to maintain X-POP for 7 days. ACPS yields 3600 lbs/day of contaminants. RCS yields 20 lbs/day of contaminants.

Any fine pointing beyond base shuttle stability will have to be designed into the observing system. ACPS can deliver 0.5 degree stability; RCS 0.2 degree stability; CMG 1 arcmin stability.

ACPS system presumably is already available on the orbiter. It is not restricted to X-POP attitude. It required high weight and volume allowances for fuel. It yields much possible contamination. It involves the use of hazardous materials and it involves possibly complex problems of payload integration (addition of fuel tanks in payload area, etc).

RCS involves minimum weight per mission at low cost. However, it requires additional orbiter systems (unless we insist on its use in all shuttles). 50% by weight of its contaminants are non-programmable. It is restricted to X-POP inertial attitude. Integration of RCS into the system could increase turn-around time. It also involves use of hazardous materials.

CMG introduces little contamination (except vibration, for example). It comes integrated with the payload. It is reuseable for both 7 and 30 day missions and it provides the best (1') base stability.

The Martin-Marietta study recommends the use of 3 double gimble skylab CMG's with gravity gradient dump of accumulated momentum. This minimizes contamination, simplifies interfacing with the shuttle system and allows use of the same system on both 7 and 30 day missions.

Problems of integrating RCS with the orbiter are probably irrelevant since about 2/3 of all experimenting disciplines will need fine base pointing capability. An RCS system should be on all shuttles. The Shuttle thermal environment is not too bad for telescopes. Temperature rises mainly during ascent and drops rapidly back to a nominal value in orbit.

Acoustic problems may be more difficult. The payload "sees" 155 db maximum acoustic level during ascent. It should "see" less than 140 db. This can be accomplished by adding acoustic shielding. However, problems of resonance at about 60 Hz (or any other frequency) could be very important.

Available data rates should reach 250 KBPS (TDRS). However, with a normal single link through NASCOM one presently gets 5 KBPS. Supposedly we can use

the total data transmission capability of the shuttle 70% of the time (is that the 70% when shuttle is out of contact with ground stations ?).

Our main concern is with the case of a 28° orbital inclination. However, we should not rule out using sun (or anti-sun)-synchronous orbits. One could use the shuttle as a sun-shield and observe the hemisphere around the anti-sun. We should not discount use of high-inclination orbits.

ROLE OF MAN

The working group strongly feels that man must have relatively easy, periodic access to the astronomical equipment if the full value of the shuttle sortie mode is to be realized (see discussion of "mission requirements" above). Such access does not necessarily have to be available while the telescope or other instruments are operating. Access would be required for functions such as changing film, adjusting slits, focussing, changing filters (filter wheels may compromise an instruments effectiveness) and repairing or overriding failed parts. It is of greater importance to have access to the instruments attached to telescopes (spectrometers, photometers, cameras, etc.) than to the main telescopes themselves, that is, access required to the area of maximum complexity.

It might be possible to use mechanical manipulators (of the type used in nuclear physics) for loading or retrieving film, for example. It is not clear how useful such devices would be as compared to "shirt-sleeve" access capability.

Principal objections to remote operations versus manual access revolve around cost, flexibility and efficiency. Shuttle cost savings come largely from flying ground-based, laboratory type equipment. Such equipment does not come built for remote operation. Use of this kind of equipment requires manual access. Otherwise costs become very high. Also the system must allow for simple instruments to be mounted in the telescope focal plane, instruments that anyone in or out of NASA can build. Such instruments must be accessible. A single instrument such as LST must be automated, even with manned servicing available. However, the variety and flexibility of instrumentation to be carried on sortie missions would make such automation very expensive and vastly increase interface complexity. Target of opportunity mode observations, requiring only one or two observations, would become difficult or impossible without ready access. If we don't have manual access, the role of the experimenter on sight becomes diminished and some of the "advertised" attractive features of the shuttle are lost.

Further discussion centered on the role of man on the ground and on board the spacecraft in planning and using the equipment. For example, should the

principal investigator remain on the ground or go into orbit? Should the person in orbit be merely a technician or should he be allowed to exercise scientific judgment? Could not most scientific judgements be made on the ground (provided adequate ground-to-sortie lab communications were available)? What can man do in the orbiter that is not better done automatically? Do we really want men moving around if we are trying to maintain 0.1 sec stability? Could not manual adjustment of an experiment knock off alignments, etc.? The discussion proceeded as follows: We intend to use man primarily as a scientist in space.

Where is the payload specialist to come from? Mainly the scientist himself or a colleague flies with the payload.

Would we not need representatives of both institutions in joint missions?

We actually need 4 payload people rather than 2, with 2 two-man shifts per day. There should be one scientist/astronaut (mission specialist) to coordinate pilot functions and scientific work. In a two-man crew that is more expensive than with four men. I think there should be one mission specialist and 3 payload specialists. In a dedicated mission, the mission specialist should be a NASA man most familiar with the telescope (analogous to a night assistant). Of course the extra men will require extra expendables weight.

The basic crew as now envisioned includes a commander, a pilot, a mission specialist, a payload specialist and passengers not connected with operations. The payload specialist could be the principal investigator and the mission specialist would have the duties of a flight engineer. Mission specialists do not have to be fliers or from the astronaut office but should by NASA people. We fully intend to fly principal investigators and not to relegate their tasks to astronauts. 3g's during ascent is not a problem for the average person. Zero g's may make you "seasick" for one day but that is all.

I strongly urge that we opt for four payload specialists (e.g., one per experiment) even at the expense of payload weight.

The Greenstein report stresses automated ground-based observing. Are we not taking a step backwards in promoting such a role for man in space?

But this only means man has sophisticated equipment to allow <u>his</u> observing to be more efficient. These are not unmanned equipment.

I don't agree with the analogy to the Greenstein report. The emphasis there was on extending the capabilities of ground-based equipment to a new level. For the shuttle we have been considering very simple, even primitive astronomical

equipment. We are not yet at the stage of pushing our capabilities from the shuttle to their technical limits. I see no virtue in the automation of such primitive equipment just for the sake of automation.

At present only a single voice channel is planned. This is not adequate for control of the observing from the ground. There is little observing decision making that could not be carried out by a "night assistant" in orbit.

Some quick decisions are best made from orbit some best from the ground. The best "night assistant" is one of the people who built the equipment.

I would prefer to keep the scientist and his working team on the ground and link him to the shuttle with very good voice communications.

That should be left for the individual program to decide. Would you prefer Helmut Abt or a night assistant? Abt wouldn't want to fly with every astronomical flight.

Start up and check-out time on new payloads might be lengthy for a general night assistant.

We must insist on an adequate voice link to allow the possibility of scientific decisions to be made on the ground. We must keep open the possibility of scientists going along with their payloads. Possibly we might give scientists on the ground veto authority over the scientist in orbit.

How many experiments would have to be run simultaneously? Efficiency probably requires more than one at a time. Could only one or two scientists handle many experiments, some not their own? Our experience with Mariner is that people can respond to contingencies in the observations quickly, but the system itself may be slow to react. We can probably expect to get one turn-around per seven day mission in terms of responding to data and changing observing modes or schedules.

On Convair-990 P.I.'s sometimes fly but the more usual situation involves only engineers, technicians and graduate students.

I recommend that we devise systems at reasonable cost, with maximum efficiency, that are simple. I want a minimum of perturbation of the experiment by man and a maximum of pre-planning and automation of observing sequences. We should have man there only to close the loop, not as a major driver or decision maker. He should not be manually slewing the telescope.

This clearly depends on the kind of observing involved. A scientist who has designed a small, specialized payload for a target of opportunity will likely be the most competent person to use it. More routine observing with facility instruments might be left to technicians. However, no technician will have the depth of understanding of what is required in a given observing program than the scientist involved has. One might well ask why we can't entrust all our observing in ground-based observatories to night assistants.

I want to emphasize again the need for high data rate communications that allow a quick look by men in orbit and initial real time transmission to the ground. One could then use mini-computers to compare the actual data with his anticipations as to how the data might look, in order to allow small changes in observing mode to be made on the very next orbit if necessary.

How similar are shuttle operations to those on C-141 or 990 ? In both, men do go up, they can make repairs and real-time decisions, they can fly with off-shelf equipment (although not so much on the shuttle). However, the airplane can accommodate many more people, the airplane flys 6-8 hours not for days and the airplane contains an environment most of us can easily adapt to. The 141 is more like a dedicated facility, while in the 990 many instruments can be flown for targets of opportunity. Frequently the shuttle is casually compared to 990 or 141 and this may not really be valid. The Lear jet may be a better analogy, since it flies at higher altitude with a smaller crew, etc. The cost of the shuttle is vastly different from that of the 990. Using this analogy invites that cost comparison.

Any complex equipment requires two men to operate it — a chief operator (the scientist most interested) and a systems monitor.

One approaches use of a 16" telescope more casually than that of a 200". A similar analogy applies between the airplane and the shuttle.

I would like to advance the analogy with the more relaxed Ames system of observing rather than with the highly structured and planned skylab observing.

DATA PROBLEMS

Data handling problems of concern include the need for adequate voice links with scientists on the ground, the capability for quick-look evaluation of data via small computers or in-orbit development of photographic materials (do we need a dark room on the shuttle ?), interfacing problems related to recording and reduction of data (do we need a master computer or a master data recording system in the sortie lab or should such facilities be part of individual experiments ?), etc.

The working group strongly emphasizes the need for essentially continuous voice contact and data links between the sortie lab and the ground. This will leave open to the principal investigator the option of remaining on the ground while still being able to exercise some control over the experimenting done in orbit. It will allow scientists and technicians in orbit to seek advice quickly from colleagues on the ground. It will allow data to be evaluated on the ground quickly so that decisions about observing mode or schedule changes can be made quickly and with flexibility.

Experimenters in the sortie lab should be able to see some of their results nearly in real time to confirm that observations are being carried out properly, that instruments are focussed, etc. This applies even to photographic data. It would not be desirable to develop all film in orbit, but the capability to develop samples is essential. Such photographic problems in orbital work will be common to many disciplines and should be thoroughly investigated. Of course the correctness of exposure times could be checked with an exposure meter. The simplest solution to the problem of checking out photographic data in real time might be to install a simple Polaroid back on each piece of equipment. This would give simple focussing information, verify correctness of target, etc., without involving complex and messy dark room development procedures. Nevertheless, the necessity for more sophisticated photographic development facilities on board the shuttle should be further investigated.

The working group strongly feels that it is not economically feasible to develop a single computer or a single data storage system that will perform all necessary tasks for all observers. Interfacing with such systems could be very complex. It is recommended that each experiment be self-sufficient with regard to data storage, data evaluation and computer functions. A possible exception might be the presence of a small general purpose computer in the sortie lab of the sort discussed previously by Lane.

FLIGHT SCHEDULES AND TIMING

Dedicated optical/UV astronomy missions must be flown more than once per year and flights of 30 days rather than 7 days duration would be of great use, if the shuttle sortie mode is to be cost effective. We must have the capability to respond to astronomical events of great importance (novae, comets, etc.) at least with "piggy-back" payloads on a very short time scale.

MISSION AND INSTRUMENTATION RESPONSIBILITY

Who is responsible for designing and building instruments, etc. ? We should provide some basic instruments that everyone can use and leave it to the general community to develop smaller specialized instruments.

Should the facility be NASA-developed or should another Kitt Peak, JPL or LST be set up? Such a national facility has been proposed for LST.

NASA should interact directly with those who will use the instruments. We should supply telescopes, basic instruments, etc. and let outsiders supply other things.

The problem is that some people don't want too much in-house power in the design of instruments.

Do we wish to have a national or an international facility? Sometimes international programs are simpler to run than those dealing just with Americans.

If the set-up is like AURA, however, the international problem becomes complicated. Who are members? How do they contribute to funding, etc. ? "National" or "international" implies something about the use of the facility rather than its control. IUE is internationally controlled. For the shuttle everyone might propose observations rather than equipment.

The next phase of the workshop involves getting the university community incorporated into the planning. What is an effective way to do this? First provide the institutions with support. Propose an AFO similar to that JPL sent out for outer planets missions, etc. This is to get people involved in planning missions, and is not a promise that they would get preferential treatment is use of the data.

We could form a shuttle sortie advisory panel of astronomers. This involves someone in NASA picking experts in various fields to participate. Such a committee has special biases. Have you picked a wide enough spectrum of people to deal with engineering, science, analysis of data, etc. ? The AFO's for outer planets work provided little funding for hardware, etc.

Some funding is provided for analysis of data, basic research on which analysis is based, etc.

If we can agree on a basic facility and on provisions for flights then we can bring the astronomical community in to finalize observing programs.

In our airplanes we deal with three kinds of instruments: basic instruments provided by NASA, instruments proposed by outsiders but built and owned by NASA, and instruments brought in by outsiders that belong to them. The idea is fine but it seldom works. P.I.'s tend to run off with the instruments they build even when they technically belong to NASA.

For 20 flights of the shuttle with seven basic instruments we're talking about 2×10^9 dollars expenditure. As a guideline we should plan to spend no more than \$50,000 - \$100,000 for each auxiliary instrument (comparable to cost of rocket or ground-based instruments). We can't afford peoples' salaries over 7-8 year lead times for building instruments. We should start building instruments only about 1-1/2 years before a flight. Perhaps we could involve an advisory group at low cost without actually building prototype instruments.

Our next set of meetings is to involve university people. How do we get their input into the system? Given the group, how do we use them most efficiently? Perhaps we should just build the thing and let them beat the door down to use it.

APPENDIX I

REFLRENCE MATERIAL USED BY GROUP

APPENDIX I

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PRELIMINARY REPORT OF THE PLANETARY ASTRONOMY WORKING GROUP

CONTENTS

	Page
INTRODUCTION	14-1
SHUTTLE MODES	14-1
SHUTTLE SORTIE MODES	14-2
SORTIE CRITERIA FOR PLANETARY ASTRONOMY OBSERVATIONS	14-4
GENERAL DISCUSSION	14-5
PLANETARY ASTRONOMY EXPERIMENTS	14-9
APPENDIX A SMALL PLANETARY TELESCOPE	14-A-1
APPENDIX B INFRARED PLANETARY TELESCOPE	14-B-1
APPENDIX C MILLIMETER AND SUBMILLIMETER PLANETARY RADIO TELESCOPE	14-C-1
APPENDIX D COMETARY MATERIAL SIMULATION EXPERIMENT	14-D-1

PRELIMINARY REPORT OF THE PLANETARY ASTRONOMY WORKING GROUP

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INTRODUCTION

The Planetary Astronomy Panel considered the possibility and desirability of using the space shuttle in the sortie mode for planetary exploration. They interpreted planetary astronomy as including observational studies of all bodies in the solar system, excluding the sun. Included are the planets, their satellites, comets, asteroids, meteoroids, and even the earth when considered as a planet. Some solar observations may be necessary to obtain comparison spectra.

Although this workshop was directed towards use of the space shuttle in the sortie mode, it would have been shortsighted not to examine briefly the use of the other possible shuttle modes for planetary studies. It was also important to consider the use of the shuttle sortie mode in relation to other approaches available for planetary exploration. It was realized that the shuttle sortie mode should only be considered for planetary astronomy if it provided a significant addition both in knowledge and in economics to the presently planned program of planetary exploration.

SHUTTLE MODES

According to our understanding of the space shuttle concept, it can be used in any one of three modes: (1) as a carrier vehicle for spacecraft to be boosted into another trajectory using a second propulsive stage, (2) as a launch vehicle and possible tender for earth orbiting spacecraft, and (3) as a short-term orbiting platform for scientific payloads which may or may not be rigidly attached to the shuttle itself. Each of these modes is potentially valuable for planetary exploration. The most obvious is the use of the shuttle as a carrier vehicle for planetary spacecraft which are then boosted into the appropriate trajectory by

one or more upper stages included as part of the shuttle payload. This mode was not considered by the panel.

The second mode, in which an earth-orbiting satellite is placed into its orbit directly from the shuttle, was considered to a limited extent by the panel as it represented a logical extension of the sortie mode and vice versa. It was assumed that the orbiting spacecraft could be visited by later shuttles to make repairs or modify the orbiting payload. Two representative experiments were considered which would be ideal for this mode. These experiments represent a logical growth from the sortie mode payloads discussed later in this report. The scientific justification is the same as given for the sortie-mode payloads with additional justification that the larger instruments would provide significantly greater data-gathering capability than possible with the sortie mode instruments.

The first instrument considered was a 3-meter diameter infrared telescope. It would basically be an infrared version of the LST but with a degraded mirror surface accuracy. The new requirement would be for a mirror diffraction limited at 5 micrometers. The telescope, which would be used for high resolution infrared spectroscopy and imaging, uses the revisitation capability of the shuttle to replenish cryogenics and possibly to change auxiliary instrumentation. As presently conceived for planetary observations, there would be no need to cool the entire telescope other than by radiation. It would, however, be necessary to cool the detectors. Use of the telescope for planetary observations would require some modifications from the LST design such as providing for the possibility of observing objects close to the sun, approximately ten degrees from the limb. Otherwise most of the LST hardware could be used, which makes the infrared telescope relatively economical.

Another example of a freely-orbiting planetary astronomy spacecraft is a very large diameter (10 meters or greater) millimeter or submillimeter radio telescope. The antenna could be assembled from separate pieces in orbit or stowed in a folded form and then unfolded prior to orbital insertion. The revisitation mode of the shuttle could be used to interchange front ends (detectors and cryogenics) for the system.

SHUTTLE SORTIE MODES

After careful evaluation of the relative advantages and disadvantages of the shuttle as a platform from which to perform planetary observations, it was determined that the shuttle in the sortie mode could provide a valuable addition to the overall program of planetary exploration. The real value cannot be determined, however, until the ease or difficulty of working in the shuttle mode is better understood.

Up to the present time two approaches have been used in the planetary exploration program. The obvious approach was to send spacecraft directly to the planets so they could be studied in detail. The other approach was to make maximum use of astronomical-type observations from the surface of the earth. The second approach is much less expensive but can never provide the detailed information possible from a planetary spacecraft.

Use of the shuttle sortie mode provides a new approach which, while sharing some of the disadvantages of both of the other approaches, has several unique advantages over each, some of which are discussed below.

Compared to ground-based observations, use of the shuttle eliminates the following problems:

- Seeing — Limits the maximum spatial resolution that can be observed from the ground.
- Weather — Prevents or limits continuous observations of astronomical bodies from the ground.
- Sky Brightness — Limits the magnitude of the faint objects that can be observed from the ground.
- Limited Observable Wavelength Range — Prevents ground-based observations in the ultraviolet and throughout most of the infrared spectrum.

Compared to planetary flight missions, use of the shuttle permits:

- Continuous Observations — Observations of planetary bodies over extended periods of time from weeks to years.
- Interchangeability of Instruments — New instruments can be developed and used in an evolving program of planetary observations while planetary spacecraft are limited to the complement of instruments they carry.
- Short Lead Times — Changes in instrumentation can be made within a matter of weeks or months and can be based on the results of previous observational results.
- Observations of Objects Not Included in the Flight Program — As the number of planetary missions is limited, not all interesting bodies in the solar system can be included. However, almost all objects will be observable from the shuttle.

In addition to the advantages mentioned above, the shuttle presents an ideal platform on which to test instrumentation prior to its use on a planetary spacecraft. The conditions on the shuttle duplicate as closely as possible the conditions that will exist on the planetary spacecraft during the mission.

SORTIE CRITERIA FOR PLANETARY ASTRONOMY OBSERVATIONS

As planetary astronomy observations are basically similar to other astronomical observations, a natural question is, "Why not use a general astronomical payload to observe objects in the solar system?" Although it is possible to observe solar system objects with a standard astronomical telescope, there are sufficient unique planetary requirements to warrant either the design of specialized payloads or require that, in the design of the general astronomical instruments, serious consideration of the requirements for planetary observations be included from the very beginning. Among the more important requirements for planetary observations are the following:

- Pointing — As most solar system objects are extended sources rather than point sources, it is necessary that the telescope can either be fine pointed and guided at an extended source or be accurately offset pointed at a variable rate from a point source.

- Stability — Imaging of solar system bodies requires the ability to point the telescope to an accuracy of 0.1 arc seconds for a few seconds up to several minutes while other types of planetary observations require pointing to an accuracy of approximately 5 arc seconds for periods up to half the shuttle orbital period. The capability for such fine pointing will have to be built into the telescope itself.

- Near Sun Viewing — Many solar system bodies are of greatest interest when they are located only a few degrees away from the sun. Also, Mercury and Venus are always found relatively close to the sun. Thus, a planetary telescope must be designed with adequate sun shades and thermal controls to permit observations of objects up to within about 10 to 15 degrees from the sun. In some cases, the use of a solar occulting disk might be considered.

- Narrow Field of View — In planetary astronomy, the interest is generally in observing one object at a time, and therefore the emphasis is on a narrow field of view, generally one minute of arc across or less. This requirement plus the desirability for large linear scale at the focal plane result in the choice of focal ratios from f 15 to f 30 for planetary telescopes.

- Entrance Iris Diameter — As many important planetary astronomy observations require using the integrated light from the whole planet, which may be up to 30 seconds of arc in diameter, it is necessary that the entrance iris diaphragm of the spectrograph or other instrument be capable of accepting such a large angular size.

- Very High Dispersion Spectroscopy — Determination of the composition and physical properties of planetary atmospheres from their infrared spectrum requires spectra with resolutions on the order of 0.1 wave numbers. Such resolutions require the use of very high dispersion spectrographs. The resolutions are much higher than used in stellar spectroscopy.

- Specific Flight Times — Observational programs on many solar system objects are quite different from most stellar programs in that they require a series of observations over a period of time to study time-varying phenomena, or they have to be made at specific times when a planet or comet is located at a certain position in its orbit. Thus, scheduling of solar system observations is, in general, more critical than for non-solar observations and repeated flights of the same instrumentation are often required. This requirement suggests the development of planetary astronomy payload packages which can be flown frequently on non-dedicated flights of the shuttle in the sortie mode in addition to the development of a dedicated planetary astronomy payload.

GENERAL DISCUSSION

The panel, before coming up with specific examples of planetary astronomy payloads, discussed at length the material on the shuttle which had been presented during the previous day and a half. While there was considerable discussion on details of the presentations, the main concern was with what the panel members considered as several problem areas in the use of the sortie mode for planetary astronomy. The general areas of concern were the shuttle environment, the available shuttle services, and the anticipated limitations of shuttle activities.

Specific concerns were:

ENVIRONMENT

Contamination

Volatiles such as water, that are presently planned to be released from the spacecraft, produce an environment in the vicinity of the spacecraft that is intolerable for many planetary astronomy observations.

Radio Frequency Interference

The radio frequency environment on the shuttle is critical if an attempt is made to do millimeter or submillimeter radio astronomy. This environment is not known as yet, but every attempt should be made to keep the interference to a minimum.

SERVICES

Pointing and Stability

All potential planetary astronomy experiments require pointing accuracies to within a few seconds of arc and instrument stability such that accurate pointing can be maintained for periods up to one half the orbital period. In some cases, pointing must be maintained to an accuracy of 0.1 seconds of arc for periods up to one minute. It is understood that the fine pointing will have to be accomplished by the telescope itself, but it is required that rough pointing be available from the shuttle, possibly through the use of a stabilized platform.

Power

The total amount of power available for the science payload from the shuttle is inadequate for most planetary astronomy experiments. The desire to make use of laboratory-type equipment makes this problem even more acute. All the specific planetary astronomy experiments described later require more power than appears to be available.

Telemetry

The possibility of on-board data recording reduces the telemetry requirement significantly if the payload specialist is qualified to judge the scientific value of the data being received. However, if the payload specialist is not extremely knowledgeable in the details of the experiment, it will be necessary to maintain direct, real-time communication with an investigator on the ground and provide him with samples of the data being obtained. Such a mode of operation would overload the planned telemetry capability.

Crew

Ideally the crew should include as payload specialists men who are intimately familiar with the details of each experiment. However, as this ideal does not appear realistic, serious thought should be given to the number and background

of the payload specialists as well as what they can do or should be expected to do during the mission. The principal investigator should be informed from the very beginning of what assistance be can expect from the whole crew and, in particular, from the payload specialist.

LIMITATIONS

It is in this area that the greatest differences between the basic shuttle sortie concept and prior experience with manned space missions seem to exist. The concept of the shuttle sortie appeared, to the panel, as an attempt to carry out science at the lowest possible overall cost. It was suggested that investigators might make use of laboratory-type apparatus aboard the shuttle. However, little discussion was presented on such important matters as safety requirements, equipment reliability, possible restrictions on the use of various types of materials, the possibility of realistic equipment repair (for example, can jobs like soldering be done during flight or must repair be limited to replacement of plug-in units?), ease and frequency of EVA activity, amount of documentation and other similar items that directly affect the complexity and, hence, the cost of individual experiments. Serious concern was expressed that carryover of the previous manned space flight philosophy to the shuttle operation would eliminate all the expected economics of the program.

INFORMATION NEEDED BY POTENTIAL INVESTIGATORS

The panel was extremely concerned that much of the material needed by potential investigators was not emphasized in the presentations while a great deal of material was presented which was of little use or interest to an investigator. The panel members did not, however, have time to study in detail all of the written material presented at the meeting and, therefore, their remarks are restricted to the oral presentations. It was considered that the subjects listed below should be covered in any presentations to potential investigators:

Trajectories

What is the nominal shuttle orbit and what variations are possible? What are the penalties incurred by using non-nominal orbits?

Payload Interfaces

What power and telemetry are available for the experiments? What is the maximum pointing capability and stability that can be provided by the shuttle, including the use of possible shuttle-furnished stabilized platforms?

Shuttle Environment

What is the thermal, magnetic, radio frequency interference (et al.) environment that is normally associated with the spacecraft and what is the possibility and impact of trying to modify this environment? Within what limitations, if any, must equipment be designed so as not to interfere with other investigators?

Instrumentation

- Testing — What environment does the equipment have to be designed for and what preflight tests will it have to undergo?

- Reliability — What will be the result of equipment malfunction? The real possibility of reflight in case of malfunction will considerably reduce the complexity and, hence, cost of experiments.

- Repair — What types of repair in flight are possible and how does the equipment have to be designed for repair in flight? What test equipment will be available on the shuttle?

- Safety — What safety requirements must be met and what limitations do they place on the use of "laboratory" equipment? Do the safety requirements eliminate or restrict the use of any particular materials such as cryogenics?

- Documentation — What detail is required?

Integration with Shuttle

Are mockups of the sortie cans and pallets available for use by the investigator? How long before flight will the integration of the entire payload be made? When will the investigator start to be involved with members of the specific crew that will fly his experiment? How familiar can he expect them to become with his experiment?

In-flight Operation

What will the operational schedule be? What duties can he expect of the payload specialist? What will happen as a result of equipment malfunction? What opportunities will he have to sample the data in real time and what effect can he have, at the last minute, on the observing program?

PLANETARY ASTRONOMY EXPERIMENTS

GOALS AND OBJECTIVES FOR THE DISCIPLINE FOR THE DECADE OF THE 1980's

The planetary astronomy experiments will increase our knowledge and understanding of the solar system with emphasis on studying its origin and evolution by means of astronomical observations of its members, excluding the sun. The shuttle program will both supplement and complement the planetary flight program and the ground-based planetary astronomy program. Specific objectives include study of time varying planetary features such as clouds, detection of the molecular constituents of planetary atmospheres, determination of physical properties of planetary atmospheres and surfaces, and detailed study of transient solar system phenomena such as comets.

IDENTIFICATION OF THE POTENTIAL CONTRIBUTIONS THE SORTIE MODE CAN MAKE TO SPECIFIC DISCIPLINE GOALS AND OBJECTIVES

- Moderate aperture telescopes on the shuttle in the sortie mode can be used to obtain reasonably high resolution images of the planets and other bodies, free of the distorting influence of the earth's atmosphere. They are especially useful in the near ultraviolet and near infrared.

- Observations throughout the infrared spectrum, not obtainable from the ground or from the C141 aircraft, of planetary atmospheres and surfaces will yield information on chemical composition and physical properties of objects.

- Observation of millimeter and submillimeter radiation from solar system bodies free of the influence of the earth's atmosphere, which completely absorbs the radiation over much of this wavelength range, will be useful in compositional studies of planets, satellites and comets.

- Simulation of processes that may be occurring in the solar system may be made in order to test hypotheses on the origin of observed but unexplained phenomena. For example, theories concerning the parent molecules that produce the observed radicals in comets may be tested through the study of artificial comets.

DESCRIPTIVE TITLE OF SORTIE MISSION OR MISSIONS REQUIRED FOR EACH OF THE POTENTIAL CONTRIBUTIONS LISTED ABOVE (NOT NECESSARILY ALL DIFFERENT)

- Planetary Astronomy — Small Telescope Mission
- Planetary Astronomy — Infrared Mission
- Millimeter Planetary Astronomy Mission
- Cometary Material Simulation Mission

DESCRIPTIVE TITLES OF SORTIE MISSIONS FOR WHICH REQUIREMENTS AND CHARACTERISTICS ARE OUTLINED IN ATTACHED APPENDIX

- Small Planetary Telescope
- Planetary Infrared Telescope
- Millimeter and Submillimeter Planetary Radio Telescope
- Cometary Material Simulation Experiment

OUTLINE OF THE PROPOSED TOTAL FLIGHT SCHEDULE OF SORTIE AND NON-SORTIE MISSIONS NEEDED TO MEET THE DISCIPLINE GOALS AND OBJECTIVES (Table 14-1)

Table 14-1

	(a) 1 meter telescope	(b) 3 meter telescope-IR	(c) mm & sub-mm radio telescope	(d) comet simulation
1979	1		2	
1980	2	1	2	1
1981	2	1	2	
1982	2	2	2	1
1983	4	2	2	
1984	4	2	2	1
1985	4	3	2	
1986		3	2	
1987		3	3	
1988			3	
1989			3	
1990			3	

NOTE: Most of these missions need not be dedicated missions. Combination of two or more planetary instruments on a single flight or combination with other astronomy experiments is possible and may be preferable.

APPENDIX A

SMALL PLANETARY TELESCOPE

APPENDIX A

REASONS FOR THE SORTIE MODE

A f20 1-meter diffraction-limited telescope in earth orbit is equivalent to the 5-meter (200-inch) ground-based telescope. The telescope can be used to look at faint asteroids and to search for faint satellites and for comets far from the sun. A direct photograph of the sky, with a long exposure on fine-grain emulsion, would permit one to check for asteroids very near to the sun. (With the 5-meter on the ground one is limited by the sky brightness.) With a telescope in orbit, one has the great advantage of being above the air glow and seeing problems do not exist. This telescope would permit observations near the sun. For example, one could observe Saturn and the rings at small phase angles (near the sun). Photometry of the rings would enable us to learn something about the fine structure and particle size.

The advantage of doing this from earth orbit is that one could observe from small phase angles not possible in the MJS proposed photometry experiments. Both types of missions would actually be useful in a complementary relationship. An orbiting telescope would give a greatly improved measurement of the zodiacal light, because with a 25 cm aperture and a 1-meter telescope one can exclude bright stars from the field of view. From the ground, the zodiacal light is about equal to the background light from the stars. Another observable target is cometary nuclei. By conventional techniques, these are estimated to be less than 10 km, but with the 0.1 sec. of arc resolution, this upper limit on the size could be lowered to 1-2 km. The one meter telescope would enable one to do bolometry of the planets and obtain better estimates of the total energy balance. In order to improve bond albedos of the planets, we really need to know how much solar energy is incident on them. This telescope could be used to compare the sun with a standard lamp to find the brightness of the sun (solar constant). A double monochromator and two photomultipliers could be used to accomplish this. This telescope could be used to measure the occultation of a star by a planet. One should look at 2800 Å, in two strong Mg lines (analogous to the H and K lines of Ca) where the sun is black and therefore the planet is also black. One could do spectroscopy of faint satellites such as Titan or the Galilean satellites much better with a 1 meter telescope in orbit than with a larger telescope on the ground. The 1 meter instrument could be used to do photometry of asteroids over long periods of observation to learn the orientation of their spin axes.

The telescope could be used to patrol weather systems on other planets. On the cloudy planets, one could monitor the variation in abundance of both major and

minor constituents from the variations in their spectra with time. Ultraviolet photographs of Venus, taken continuously and further into the UV than is possible from Earth, would show the circulation patterns in the upper atmosphere of Venus. One could measure the variation over local areas of the planet much better than from the ground where seeing limits the angular resolution to about 0.5 sec (or occasionally 0.2 sec) the orbiting telescope could measure 0.1 sec. Venus and Jupiter are known to exhibit considerable cloud activity, which should be monitored continuously, and the outer planets may be as interesting to study as well; a patrol of them should be begun and continued for a number of years. The variation in the abundance of H_2O on Mars should be patrolled also.

The photometry of the standard stars, used as a calibration for photometry of planets, should be repeated because corrections for telluric extinction are of doubtful accuracy in many cases.

REQUIREMENTS WHICH THIS TYPE OF MISSION PLACES ON THE SHUTTLE

- Length of Flights — maximum observing time; 7-day missions are a minimum for a planetary patrol, and 30-day missions are definitely preferable.

- Orbit — depends on objects observed. The requirements can vary, and may result in requesting a very specific orbit. An exact ephemeris is mandatory (on a real time basis).

- Data Requirements — depends on observational mode. For photography (imaging and spectroscopy), if the investigator is not aboard, a TV channel (1-2 frames/sec) to the ground is essential; for photometry-polarization measurements a 10^2 - 10^3 bit/sec. rate is desirable; for interferometry, a 10^4 - 10^5 bit/sec rate is desirable. This rate would enable an investigator on the ground to "look" at the first set of observations to determine if his experiment is working properly, i.e., if the data look "reasonable" or not. For photography and photometry, the telescope may only have to be held to 0.1" for only a few minutes.

For high resolution spectroscopy of specific areas on a planet, e.g., belts of Jupiter, the telescope must be held to 0.1" for approximately 2 hours to obtain optimum results. For high resolution spectroscopy without resolution over the planet 5" could be tolerated.

- Role and Number of Personnel in Orbit - 2 or 3 — Observations on a 24 hour/day time scale should be attempted. One trained observer, a mission specialist, and a payload specialist could accomplish this objective;

the alternative is to use two "night assistants" plus a payload specialist (this option would require a higher data bit rate, so ground-based investigation can be made to determine whether data are acceptable or not).

- Stabilization and Pointing — 0.1" desired for photography; 0.5" absolute minimum acceptable for photometry. If the orbiter can only have a pointing accuracy of 0.5 degree, then an optical guidance system for the telescope is required.

- Power and Thermal Requirements — estimated less than 200 w maximum with properly designed equipment for a space mission. With present "laboratory" (non-optimized) equipment, it is ~1 kw. This represents the maximum thermal heat source. No cooled detectors are used except photomultiplier(s) cooled to from -20 to -40 C.

- Weight and Volume — for the 1 m telescope, the weight of the tube and optics is estimated to be 1000 pounds. To secure the necessary rigidity on a ground-based telescope, about 15,000 pounds of steel mounting and 10,000 pounds of concrete pier are required. Data on the structural rigidity of the shuttle and pallet are lacking, so, total weight of the telescope cannot be estimated. Volume is also difficult to estimate without a properly designed (i.e., designed for the shuttle) telescope, as it depends on the need to slew. Certainly a full hemisphere should not be needed. But how much clearance is needed to swing and how much will be provided by the shuttle is not known. An alt-azimuth mount system would be used. The primary mirror should be $3 < f < 5$; thus the tube length would be between 3 and 5 meters. As the telescope is on a pallet, exposed to space and outside the airlock, the total volume required could be anywhere from 5 m^3 (the volume of the telescope) to 100 m^3. The rigidity of the pallet again influences the volume occupied by the telescope mounting. The weight and volume of the supporting equipment are estimated to be as follows: grating, collimator, camera mirrors 500 pounds (rigid mountings are needed for these also); automatic guiding approximately 20 pounds plus 1-2 racks of equipment; photometer approximately 150 pounds if "laboratory" equipment is used plus 1-2 racks of electronics; exposure meter plus Vidar counter approximately 200 pounds if "laboratory" equipment is used, and 2 racks of electronics; photo polarimetry (two channel photometer plus polarizing device) approximately 200 pounds if "laboratory" equipment is used plus 2 racks of electronics; automatic guider approximately 30 pounds plus 2 racks of electronics for "laboratory" equipment. Note that an active guider might have to be different for coudé spectroscopy (guiding on image of planet) than for photometry (off-set guiding on an adjacent star). For planetary spectroscopy, an image rotator (3 mirrors plus drive mechanism) may be coupled to the guiding system or it could have its own rotation

system; this weighs less than 1 pound and occupies perhaps 10 cubic inches. A magnetic tape recorder and a voltage-to-frequency converter for photometry; cassegrain scanner to use for data with a low signal approximately 50 pounds and 1 ft^3, if "laboratory" equipment is used; plate holders approximately 100 in^3 weighing 2-10 pounds for photographic spectroscopy. Image tubes sensitized to different wavelengths approximately 100 pounds plus 2 racks of equipment; a wampler scanner for use at Coudé may be included. For the spectrograph, rigid mountings are used in the laboratory (4 steel I-beams 30 ft long) to obtain the necessary rigidity required to keep the spectrograph aligned. For a shuttle mission, a laser could be used to check alignment, with a detector to count fringes and a servo-system to align mirrors. A sun sensor on the boom with occulting disc could be used to serve as the sun shade to prevent sunlight from falling on the primary when observing near the sun. A small heliostat would be useful to permit the recording of comparison spectra. It is apprarent that considerable savings in both space and weight could be achieved by using the same power supply, for example, for different devices that do not operate at the same time. Similarly, active control of telescope pointing and the optical train can result in relaxing the constraints on both rigidity and weight.

- EVA Requirements — if the equipment (spectrometer, photometer, and others) are installed in an airlock.

- Correlative Measurements — none

- General Support Equipment — the shuttle, with an electrical outlet (110 V 60 cps).

- Documentation Requirements — detailed and block diagrams of telescope/equipment packages for investigator and payload specialist.

- Special Operating Constraints — good platform stability so the telescope will be able to make at least 30 min. of continuous observations of one object. Time sharing with other shuttle users should not require us to alternate with them every 5 minutes, if the orientation of the orbiter requires drastic, frequent alteration by other users.

- Contamination Requirements — the external environment should not have more than 10^{17} molecules of CO_2 or H_2O, or 10^{18} molecule of CH_4, NH_3 in the line of sight path (of assumed cross section 1 cm^2). This is a situation that could possibly arise from venting of the cabin, operation of the attitude control system, or sharing of the shuttle with a user that will release chemicals from it in these quantities. A stabilization system that

used solar electric energy to ionize Hg, instead of thrusters, would avoid the contamination problem for planetary spectroscopy.

POLICIES AND PROCEDURES TO BE CHANGED

The concept of moving "laboratory" equipment onto the shuttle presents safety hazards to onboard personnel. On the other hand, for an experimenter to have to undergo semi-astronaut training in order to have an opportunity to do "hands-on" research will discourage many P-I's from doing their own experimental work on the shuttle. This can result in having the shuttle turn into another Apollo-mission with data being taken by scientifically untrained astronauts, who have little personal interest in obtaining data of high quality, a method which is ineffective both in scientific return and in cost.

ESTIMATED USER COMMUNITY

20 to 100 people

INTERFACE WITH USER COMMUNITY

Committee to evaluate proposed users of NASA equipment, and to insure compatibility of users' instrumentation with existing instrumentation.

FUTURE ACTION

Begin design of telescope and guidance system, with maximum interaction between structural and optical engineers and designers of the telescope and the shuttle systems engineers. More knowledge of the characteristics of the shuttle has to be made available to the telescope designers. Similarly a knowledge of the users' requirements may influence the design of the shuttle.

APPENDIX B

INFRARED PLANETARY TELESCOPE

APPENDIX B

DESCRIPTION

A 3 m diameter telescope to cover wavelength range from 5 to 300 micrometers.

REASONS FOR THE SORTIE MODE

In the field of planetary research infrared spectroscopy, broad band radiometry, and infrared imaging from the ground as well as from spacecraft have been the main sources of information. However, ground-based observations are greatly restricted by the transmission characteristics of the earth's atmosphere and by seeing conditions. Some relief from these problems will be realized on the C-141 aircraft; nevertheless, residual absorption by atmospheric gases, primarily CO_2, H_2O, and O_3, as well as residual seeing problems will remain. Futhermore, the telescope on the aircraft is limited in size. The shuttle provides an excellent base for infrared work on the planets, their satellites, and other minor bodies within the solar system. It overcomes completely the limitations imposed on ground-based astronomers as far as atmospheric absorption and seeing are concerned. Infrared imaging, radiometry, and spectroscopy from the shuttle could provide important information on the composition, temperature, and other environmental parameters of planetary atmospheres and surfaces.

Imaging by infrared vidicons, multidetector arrays, or single detector scanning devices promises to be an extremely useful tool for research on the dynamic behavior of the atmospheres of Venus, Mars, Jupiter, and Saturn. Infrared imaging at several wavelengths in the near as well as the far infrared may also provide excellent data on the compositional homogeneity of objects with tenuous or no atmospheres such as the moon, Mercury, Mars, and the moons of the outer planets.

Broad band photometry will be very useful for the precise establishment of planetary energy budgets. Measurements are required over the total spectral range and over a wide range of phase angles. Unfortunately, completely satisfactory phase functions cannot be obtained for the major planets without the use of flyby or orbiting spacecraft.

Spectroscopy in the infrared has so far proven to be the most extensive technique for investigating conditions on the other planets. Since most complex molecules have vibration and rotation spectra in the infrared, this special range becomes extremely important. Furthermore, the distribution of energy in the Planck

function is such that at planetary temperatures, the emission maximum occurs within this spectral range. Infrared spectroscopy up to a resolution of about 2 wave-numbers is capable of resolving many band contours. An increase in spectral resolution to a few tenths of a wave number is required to resolve the vibration/rotation structure within the infrared bands of most constituents of planetary atmospheres. Another order of magnitude would be required to resolve the line shape. It is anticipated that, in the time period of the space shuttle, instrumentation for resolving about one-tenth of a wave number will be readily available; some instrumentation of that nature is available today. Spatial resolution of about one or two arc seconds would be adequate to discriminate major zones on Jupiter, for example, and to obtain limb functions on the larger planets.

Because both spatial and spectral information is required in this wavelength region, we anticipate that a Cassegrain telescope of at least 2 m, but preferably 3 m diameter primary mirror will be required. If possible, the optical quality should be such that 80% of the 5μ radiation is contained within the Airy disk; however, a performance equivalent to a few arc seconds would be adequate for many cases. The overall telescope focal ratio should be from f/25 to f/30, with the F number of the primary mirror to be about 2.0. At the larger f/ratio, the plate factor will be about 0.3 mm per arc second. Use of a single element telescope, (e.g. an off-axis parabola), for use at longer wavelengths is an intriguing possibility.

We do not feel it appropriate to specify auxiliary instrumentation at this time. Off-the-shelf instruments currently exist to accomplish many of the objectives; however, we feel certain that better instrumentation will be available at the time of the shuttle flights.

REQUIREMENTS WHICH THIS TYPE OF MISSION PLACES ON THE SHUTTLE

- Length of Flights — Many infrared observations require long integration time. Flying spot scanners as well as spectrometers need uninterrupted operating periods of 30 - 45 minutes. Seven day flights are adequate in the beginning of the program, although longer durations are desirable. The same measurements may have to be made from several flights to observe phase effects, for example.

- Orbit — A polar orbit to follow a planet continuously for several days is attractive, but trade-off studies must be made.

- Data Requirements — The data acquisition rate will be determined, of course, by the type of experiment which is run. The current "worst case" is anticipated to be high resolution spectroscopy which will generate about

10^5 bits/second for as long as 45 minutes. It is assumed that the general support equipment will contain provision for data storage. It is not anticipated that this information will be relayed to earth, but a need is recognized for selected transmission to be made so that the ground support team can have a quick look at the experiment's progress.

- Role and Number of Personnel in Orbit — It is felt that in order to have a practical, cost-effective system, the telescope must be scheduled for continuous operation. Thus, a need is seen for two to three payload specialists to be on-board during a telescope mission, but it is anticipated that there will be some trajectory and possibly other constraints in using the telescope.

- Stabilization and Pointing — From information deduced thus far, the shuttle will have a stability of approximately 180 arc seconds if required. This should be a function supplied by the telescope and not be the responsibility of each experimenter. Stabilization to better than 5 arc seconds if required, say for some imaging experiments, will be the responsibility of the particular experimenter.

- Power and Thermal Requirements — Active cooling of the telescope system is not anticipated. However, since observations of the planets may be made when they are near the sun, especially Venus and Mercury, solar heating may become important. Studies should be initiated to determine if this will be a problem. It is anticipated that approximately 3 KW of power will be needed for this experiment. However, this does not include power required for guidance and stabilization, e.g., DC torque motors.

- Weight and Volume — The entire system, including about 500 pounds of instrumentation, could be configured to weigh as little as 4000 pounds; the telescope would occupy a cylindrical volume roughly 3.5 m in diameter and 7 m long.

For planning purposes, it is assumed that the primary is an f/2 system; the telescope is 6 m long without including the primary cell or secondary head ring. A shade of approximately 1 m must be added to the configuration so that the overall length of the telescope will be over 7 m. To be able to observe Mercury and the other planets to within at least 10° from the sun, a solar occultation disc must be deployed from the shuttle. Because of alignment consideration, the instrument should be stowed with the optical axis parallel to the launch direction. Operation in orbit thus requires that the telescope be first erected onto, or with, the secondary stabilization system supplied by the shuttle. The telescope will be of the folded Cassegrain type, or will have a Coudé focus which will reflect the beam of radiation into the laboratory. The optics should be made of a

material which will maintain its focal properties unchanged through the temperature range expected on the pallet, or provision must be made to focus the system during use.

The laboratory instrument compartment is conceived as being a cylindrical pressure vessel approximately 6 feet in diameter by 10 feet long. This unit should be stablized with the telescope. The beam of radiation from the telescope enters on the cylinder axis and can be diverted, via plane mirrors, to any of a number of experimental packages which have been installed. The compartment will normally be operated windowless so that all experiments will be exposed to the space environment. Provision should be made to close the port and to remove the pressure vessel in flight, without compromising the safety of the flight personnel, so that the on-board operator can make minor adjustments to an experiment, if required. It is desirable to have an image plane monitoring system available so the on-board operator can interact with the telescope stabilization and guiding system when necessary.

- EVA Requirements — For the telescope-instrument configuration envisioned, EVA will not be routinely required; however, EVA may be necessary to realign the telescope optics if misalignment occurs during launch.

- Correlative Measurements — It would be desirable to obtain measurements of the sun, the moon, and earth when observations of extraterrestrial planets are being conducted. These would be used for "calibrating" the data obtained. The telescope itself could be used for the earth and moon observations; a small, auxiliary thermostat would be needed for the solar measurements.

- General Support Equipment — Additional general support equipment should include cryogens (LN_2 and LHe), normal laboratory tools and test equipment, vacuum pumping capability, and general provision so the on-board experimenter can obtain a quick look at the data.

- Documentation Requirements — Currently no need is seen for extensive on-board documentation. Simple users' manuals for the various experimental apparatus will be needed; however, the ground support team should furnish instructions to solve specific problems.

- Special Operating Constraints — None

- Contamination Requirements — Because an important portion of the telescope use will be devoted to spectroscopic investigations and searches for trace constituents on extraterrestrial planets, it is imperative that no

reaction thrusters be used during an observation, and that no waste dumping, possibly exclusive of N_2 or He boil-off, be done during observations.

- Radiation Environment — No specific requirements

POLICIES AND PROCEDURES TO BE CHANGED

None

ESTIMATED USER COMMUNITY

Our only guideline for estimating the number of users for this instrument is the experience with the C-141 telescope. Over 40 proposals were received to use that instrument as a result of the first AFO. The responses to use this instrument should be similar. Use of the AFO appears to be a reasonable method for interfacing with the user community, with the understanding that potential users should be asked to advise during the design phases of the instrument.

APPENDIX C

MILLIMETER AND SUBMILLIMETER PLANETARY RADIO TELESCOPE

APPENDIX C

DESCRIPTION

A 4.5 m diameter antenna to cover wavelength range from 0.3 mm to 8 mm.

REASONS FOR THE SORTIE MODE

- The shuttle would make the millimeter and submillimeter spectrum available to astronomers in all weather conditions and in all frequency intervals. Ground-based observations are severely degraded or wiped out entirely by atmospheric absorption due to clouds, rain, water vapor, and oxygen.

- The shuttle would allow continuous monitoring of the planets independent of secant angle and atmospheric variations.

- The shuttle configuration and generous weight allowances allow one to construct an extremely flexible instrument capable of operating over 25:1 wavelength range.

- The planets are easily observed at both Northern and Southern declinations from the shuttle.

PLANETARY SCIENTIFIC OBJECTIVES

- Atmospheres — The spectral region covered by this instrument contains the most intense rotational bands of the gases making up the planetary atmospheres. These lines have never been detected. Their detection and measurement would almost certainly increase our knowledge of the composition, pressure, and thermal structure of planetary atmospheres. Some examples of molecules which are expected to be seen in this spectral range are H_2O, O_3, O_2, SO_2, CH_3CN, HCN, NH_3, CO, H_2S, and HCO_2H.

- Surfaces — The radio emission from Mercury, Mars, the moon, presumably the Galilean satellites, Titan, and the asteroids are determined mainly by the thermal radiation from their surfaces. Brightness temperature measurements are characteristic of the physical properties in the upper most layers of their surfaces. The brightness temperatures of the surfaces of the Galilean satellites and Titan are of particular interest since recent theoretical results have suggested that they are expected to be much warmer than their solar heating — equilibrium temperatures.

- Variability — Both Venus and Jupiter have displayed variations in atmospheric transparency at optical and infrared wavelengths which are at present unexplained. Observations of these planets at millimeter wavelengths may help to clarify the origin of these effects.

- Limb Effects — Brightening and darkening effects can be searched for on Venus and Jupiter.

- Brightness Temperature — Measurements can be obtained and compared with both longer and shorter wavelength data.

NON-PLANETARY SCIENCE OBJECTIVES

- Interstellar molecules

- Thermal structure of solar corona

- Radio lines of CO and other molecules in the solar atmosphere.

- Cosmic Background radiation

- Describe radio sources

REQUIREMENTS WHICH THIS TYPE OF MISSION PLACES ON THE SHUTTLE

- Length of Flights — This depends on the objectives of the mission. Variability and phase-angle variation studies might cover a period of 4 to 6 months, requiring a number of consecutive flights. Limited objective studies (i.e. several planets, limited spectral coverage) can be carried out in a one-week flight.

- Orbit — Orbit design should be such as to maximize the observing time of planets and calibration sources. For some observations (e.g., faint sources, maximum spectral resolution or phenomena with time scales of the order of one hour), a polar orbit will be required with the yaw axis perpendicular to the orbital plane.

- Data Requirements — Two modes are envisioned:

  a. On-board recording at 3.5 KBPS on magnetic tape of all relevant data and housekeeping information (one 2400' tape per day).

D

b. Real time ground monitoring to the P.I. telemetered at 0.5 KBPS

- Role and Number of Personnel in Orbit — Needed are a minimum of 2 payload specialists who are intimately familiar with the instrumentation and are trained to make astronomical observations.

- Stabilization and Pointing — A pointing accuracy of 5 arc seconds peak-to-peak is required. This is 1/5 of the diffraction limited beam of a 4.5 meter telescope at 300 microns. If the telescope is mounted in an altitude-azimuth configuration, this can be accomplished by visual (TV) acquisition of the target and subsequent gyro-lock-in as used on the Lear jet and C141.

- Power Requirements — Peak power of 1.5 KW, mean power of 1 KW is required for the following items: Magnetic tape recorder, TV guidance and control monitor, telescope gyros and torque motor control loop, dedicated general purpose computer (for tracking, data, handling, sequencing and monitoring), data display, receiver and signal conditioners, power supplies, amplifiers.

- Thermal Requirements — Instruments outside of sortie can: -50°C to +20°C during operation; -100°C to +100°C inoperative.

- Weight and Volume —

Table 14-C-1

electronics (in can)	3000 lb	5000 cft
cryogenics (including container)	250 lb	50 cft
telescope (4.5 meter diameter parabolic disc f/1.5) incl. mount and torque motors	6000 lb	3000 cft
Total	9250 lb	8050 cft

- EVA Requirements — None. The front ends (receivers) are placed into the prime focus position of the antenna by manipulator arms attached to the shuttle. Receivers are stored in the sortie can and passed through an airlock to the telescope.

- Correlative Measurements — none required.

- General Support Equipment — none required.

- Documentation Requirements — Mechanical and circuit drawings of finished instruments are prepared but not carried on board. Modular layouts with detailed cable assignments and equipment start-up and turn-off procedures are carried on board.

- Special Operating Constraints — none

- Contamination Requirements — 10^6 ppb sufficient in the can. Contamination due to thrusters must be evaluated.

- Radiation Environment — unknown but of potential concern.

POLICIES AND PROCEDURES TO BE CHANGED

The use of laboratory instrumentation is essential to keep the cost down. Use of 110 volt 60 Hz power may not be the most efficient, but it is most effective to keep instrumentation cost to minimum.

ESTIMATED USER COMMUNITY

We anticipate a large demand from planetary, solar, galactic and extragalatic astronomers from both NASA centers and universities.

INTERFACE WITH USER COMMUNITY

Very similar to that of a national facility (e.g., CV 990 or Kitt Peak): User handbook, user-developed instrument, user requests observing time, bi-yearly meeting of selection committee.

FUTURE ACTION

Increase SRT funding for shuttle-oriented hardware.

APPENDIX D

COMETARY MATERIAL SIMULATION EXPERIMENT

APPENDIX D

REASONS FOR THE SHUTTLE SORTIE MODE

The object of these missions is to test theories of comet formation and the entry of cometary debris into the atmosphere by simulating cometary material in space and in meteoric flight through the atmosphere. Specific aspects of the missions are as follows:

- Mission (1): Comet Simulation — This experiment requires the deployment into orbit of a large mass of frozen material, followed by observation of the gas cloud which develops as the material is evaporated and dissociated by solar radiation. In order to closely simulate the comet and to permit ground-based observation of the gas cloud produced, a mass in excess of 10,000 lbs. for frozen material is required. This mass of low-density material will occupy a volume corresponding to a sphere about 8 feet in diameter. The shuttle sortie offers the only practical means of carrying this weight bulk into orbit.

- Mission (2): Meteoroid Entry Simulation — The objective of this series of experiments is to analyze the atmospheric entry of meteoroids of known parameters (mass, shape, composition, velocity, and entry angle) in order to determine the luminosity coefficient of meteoroids, to aid in the calibration of terrestrial-based observing systems (radar, etc.) and to compare the reaction of simulated and actual meteoroids in the upper atmosphere. The simulation would require one flight on a sortie mission where a battery of small, disposable hypervelocity guns would fire particles into the terrestrial atmosphere. The particles fired from the guns at orbital altitudes will attain meteoric velocities. A number of individual experiments incorporating different masses, shapes, and compositions can be carried out during repeated orbits of the shuttle. An observer on board the shuttle can observe the experiment to obtain photometric and spectrographic results of the simulated particles. He can furthermore make comparative spectral and photometric measurements of faint meteors in the upper atmosphere over a wide spectral range including the near UV.

REQUIREMENTS WHICH THIS TYPE OF MISSION PLACES ON THE SHUTTLE

- Length of Flights — Mission (1) The time scale for full development of gas cloud around the ice ball is estimated to be of the order of a day. Observations over the nominal seven-day sortie period will suffice to study the growth of the gas cloud.

Mission (2) Seven Day Mission Adequate

- Orbit – Mission (1) Initial experiments can be performed at low earth orbit altitudes. Because solar wind effects cannot be simulated at these altitudes, later experiments may require boosting the frozen sphere to regions outside the magnetosphere.

Mission (2) a. an 80-180 km perihelion passage desired on dark side of the earth; b. orbit spending considerable time in nightime skies preferred; and, c. repeated orbits should cross vicinity of terrestrial fixed-station observatory during experiment.

- Data Requirements – Mission (1) Images at various wavelengths are the primary data gathered. It is expected that imagery will be required in the vacuum ultraviolet at atomic hydrogen and oxygen wavelengths (using a Carruthers-type camera), and in the visible at wavelengths corresponding to CN, CH, OH, C_2, etc. Images are to be collected both from the spacecraft and from ground-based observatories (visible regions only). Periodic radar measurements of the distance of the sphere from the shuttle are also required if imagery is obtained from the spacecraft.

Mission (2) Data recorded on spacecraft and by ground stations; no transmission link is required. Data recorded on spacecraft by video tape digital recorders.

- Role and Number of Personnel in Orbit – Mission (1) An engineer or technician as payload specialist is needed to deploy the frozen sphere and operate the observing instruments.

Mission (2) One-man operation during experiment; payload specialist would initiate firing sequence and operate cameras and recorders during the experiment. After simulation experiment, only occasional attention required for actual meteor observations.

- Stabilization and Pointing Requirements – Mission (1) Pointing to 1° is required, stabilization to 1 second of arc is needed.

Mission (2) 1° required

- Power and Thermal – Mission (1) A brief power burst (about 1 kw for 10 seconds) would be needed to deploy the sphere. Operation of imaging systems (telescope and camera) would require about 100 watts. Special thermal requirements exist concerning the frozen sphere. Careful insulation of the sphere is needed to retard evaporation during launch and

boost into orbit. Provision must be made for venting gases evaporated from it during this period.

Mission (2) 0.5 kw required for full operation. No thermal requirements.

- Weight and Volume — Mission (1) Weight of the frozen sphere, and its container and deployment mechanism is estimated to be about 15,000 pounds (12,500 pounds for the sphere, 2500 pounds for associated insulation and mechanisms). Volume is estimated to be about 300 ft^3 in the shape of a sphere about 9 ft. in diameter.

Mission (2) Weight: 400 pounds, volume: 1 m^3

- EVA Requirements — Mission (1): none, Mission (2): none

- Correlative Measurements — Mission (1) The basic measurement of this experiment is to obtain monochromatic imagery of the gas cloud around the sphere. Wavelengths for the imagery are chosen to coincide with cometary emission wavelengths. A Lyman-Alpha radiation camera and a visible light camera aboard the spacecraft are needed. These could be automatically pointed and operated. Ground-based measurements, using ground-based telescopes and cameras, are essential.

  Mission (2) Photometric and spectroscopic measurements made from the sortie lab will be correlated with ground-based measurements obtained photographically, photoelectrically, and with radar.

- General Support Equipment — Mission (1) Ground-based equipment for production of the frozen sphere, storage and deployment equipment for the sphere must be developed.

  Mission (2) Hypervelocity guns, television system, photometer, video tape recorder

- Document Requirements — Mission (1) No special requirements.

  Mission (2) No special requirements.

- Special Operating Constraints — Mission (1) No special constraints.

  Mission (2) a. Must operate on dark side of Earth; b. Must operate on selected orbits in the vicinity of a ground based observatory; and, c. Will require two pounds RCS fuel to compensate for hypervelocity impulse imparted to spacecraft.

- Contamination Requirements — Mission (1) No special requirements.

  Mission (2) No special requirements.

- Other — Mission (1) This experiment will probably produce significant optical contamination for sensitive optical instruments aboard the shuttle. It should then either be deployed at the end of the mission and perform only ground based measurements, or be combined with an earth observation mission which is not sensitive to optical contamination.

POLICIES NEEDING CHANGE

Man-rating of all the equipment for these experiments is unnecessary beyond those required for safety.

ESTIMATED MAGNITUDE OF USER COMMUNITY

Thirty to fifty gound-based observers of the phenomena are expected. The phenomena will be visible world-wide to the general public, particularly the comet simulation experiment.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

Announcement of a flight and ground-based experiment opportunities are to be made to the user community.

FUTURE ACTIONS REQUIRED

A modest amount of SRT studies and planning is needed to accomplish these missions, probably an order of magnitude less than needed for an observatory-type mission.

PRELIMINARY REPORT
OF THE
INFRARED ASTRONOMY WORKING GROUP

CONTENTS

	Page
SUMMARY	15-1
GOALS AND OBJECTIVES FOR INFRARED ASTRONOMY WORKING GROUP	15-3
RECOMMENDATIONS FOR FUTURE ACTIONS REQUIRED TO IMPLEMENT IR SORTIE MISSIONS	15-8
POTENTIAL CONTRIBUTIONS WHICH THE SORTIE MODE CAN MAKE OBTAINING THE GOALS AND OBJECTIVES FOR INFRARED ASTRONOMY	15-11
SORTIE MISSION TITLES FOR CHARACTERISTICS IN APPENDICES A AND B	15-12
OUTLINE OF THE PROPOSED TOTAL FLIGHT SCHEDULE FOR INFRARED ASTRONOMY FACILITIES FLIGHTS	15-12
APPENDIX A	15-A-1
APPENDIX B	15-B-1
APPENDIX C	15-C-1
APPENDIX D	15-D-1

PRELIMINARY REPORT
OF THE
INFRARED ASTRONOMY WORKING GROUP

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SUMMARY

The goals and objectives of infrared astronomy, with certain specific exceptions, ean be achieved best by thc development of facilities which can be flown repeatedly, rather than by a variety of individual experiments that are collected together for specified missions. The effort of this Workshop has gone into describing the characteristics of a general purpose facility suitable for obtaining its scientific goals and objectives. Once developed, such facilities could be launched repeatedly, scheduling the uses of the facility instrumentation for those specific observational problems having greatest current significance.

Although it is too soon to state detailed specifications, it is already clear that two basic categories of instruments are needed: a large aperture telescope (~3 meters) operating at ambient temperature and diffraction-limited in the infrared, and a cryogenically-cooled telescope of more moderate aperture (1 meter or larger), which would minimize instrument noise in the infrared. These two instruments would attack different kinds of problems that span the 10 octaves of infrared from 1 - 1000 microns. Studies now should be done to prepare specifications (scientific and engineering tradeoffs at present are unknown) for these two classes of instruments.

Two smaller instruments, a free-flying multiband survey telescope and a liquid helium cooled telescope for studying the cosmic background, are specific experiments which can be deployed from the pallet. Although no other small experiments were considered at this time, undoubtedly the sortie mode would provide

an appropriate platform for exploratory and unique experiments as technology develops. For example, microwave detection of interstellar molecules, although falling within infrared wavelengths, was not considered at this workshop but should be included among potential experiments on the shuttle.

It cannot be emphasized too strongly that research in the infrared — unlike other spectral regions — is in its infancy and a strong SRT program is urgently needed for effective use of the shuttle sortie. These needs are described under Recommendations for Future Actions Required to Implement IR Sortie Missions, below, and one is referred to the recommendations and high priority for infrared astronomy given in the 1972 Greensteim Report.[1] Techniques developed in all areas, using ground-, balloon-, and airborne-telescopes, are directly applicable to shuttle instrumentation.

The Workshop was valuable in showing that the shuttle sortie mode could be well-suited to infrared astronomy because of the need for replenishing cryogens, and the need for man to assist in adjustment of complex and developmental equipment associated with this new discipline. In addition, the Workshop indicated potential problem areas that must be studied, such as contamination, the need for an air-lock, and access to the focal plane of a telescope.

The effective research program in infrared astronomy requires the combination of complex instruments in space and the participation of the many astronomers to systematically carry out ever evolving sets of astronomical observations. While it is not presently clear what man's role should be in the space-operation of observatories, the steps for an effective infrared program using shuttle are evident. These steps require the development of astronomical facilites. The 91 Cm IR Observatory on the C-141 aircraft is a required precursor for the development of IR facilities using the shuttle. The shuttle sortie launch costs vary little for a 7-day mission compared to a 30-day mission but the scientific return from an IR facility mission is nearly linearly dependent on the observing time; almost four times the effectiveness for the longer mission. These astronomical facilities should be developed to remain in earth orbit, whether on a manned space station or man-maintained is yet to be resolved. There is little doubt in any case that the field of infrared astronomy, which is at its inception, will yield great returns from space observations and that several decades of observational time are required.

[1] Astronomy and Astrophysics for the 1970's, Volume 1, Report of the Astronomy Survey Committee, National Academy of Sciences, 1972.

GOALS AND OBJECTIVES FOR INFRARED ASTRONOMY WORKING GROUP

Astronomical observations in the infrared portion of the electromagnetic spectrum are severely hampered by the earth's atmosphere. Absorption due to saturated molecular lines begins at roughly 1 micron, extends to 1 or 2 millimeters, and is nearly complete except for a limited number of spectral "windows". Even at aircraft and balloon altitudes where the transmission is greatly increased, observations suffer from atmospheric emission. Nonetheless, a significant number of important, sometimes startling, observations have been made in the infrared, indicating that studies in this region of the spectrum will contribute greatly to the body of astronomical knowledge and our understanding of astrophysical phenomena.

A list of objectives is given below which indicates the potential contribution of infrared astronomy to our knowledge of the universe. Although such a list will overlap with other disciplines it highlights problems pertinent to the infrared. Further information on goals and objectives in infrared astronomy can be found in Astronomy and Astrophysics for the 1970's, Report of the Astronomical Survey Committee, National Academy of Sciences, 1972; and in A Long Range Program in Space Astronomy, Position Paper of the Astronomy Missions Board, July 1969, NASA SP-213. It is noteworthy that the former publication considers infrared astronomy to be one of the programs of the very highest urgency and priority.

BACKGROUND RADIATION

Cosmic Background — In order to clarify the true nature of the universal microwave background radiation (thermal vs non-thermal), a set of accurate observations must be made in the range roughly 500μ - 1 mm, well beyond the expected peak of a 2.7°K blackbody. Such observations are extraordinarily difficult to perform, even from balloon altitude, due in part to the absorption, but primarily to the emission of the atmosphere, since the background is an extended source, with no apparent sharp spectra features. Initially, these measurements can be made with a radiometer and a set of moderate resolution filters; but if the brightness temperature in this region exceeds 2.7°K, as has been previously observed on several occassions using rocket-borne radiometers, then a study at high spectral resolution must be undertaken to identify the source of the high flux. In either case, the large and small scale anisotropies should be investigated since observations from space in this spectral region are capable of a good deal higher sensitivity than can be gotten in the microwave region.

EXTRA GALACTIC SOURCES

Infrared galaxies, Seyfert galaxies, and quasars exhibit a high flux of radiation at 10 microns, which appears to increase sharply toward the longer wavelengths which are not visible from the ground. Most of the luminosity of these objects may well be in the infrared indicating that the physical processes going on are even more violent than had been thought. Studies of these galaxies throughout the infrared are necessary to uncover the nature of the violent activity. Such studies require the high sensitivity attainable with a medium size cryogenically cooled telescope. The variability of these objects in the infrared — still unresolved — is of extreme importance, requiring a sensitive, calibrated system.

GALACTIC NON — THERMAL OBJECTS

There is as yet no observational knowledge of non-thermal infrared radiation from galactic objects, such as is available in the radio region (e.g. for supernovae). In particular, the galactic center, which is a strong radio and infrared source, is known to have a complex structure at 10 microns and is observed to emit a non-thermal radio spectrum. Relatively high spatial resolution studies at several different wavelengths are needed in the far infrared (40-200 microns) to understand the relationship between the infrared and radio objects. A large (3-meter) uncooled telescope is required for this work.

INTERSTELLAR DUST AND CIRCUMSTELLAR DUST SHELLS

The thermal radiation from interstellar dust occurs largely in the region of the spectrum ranging from 40 to 400 microns. Compact as well as very extended emitting regions have been observed at 100 microns. These objects appear to be dust clouds heated by nearby hot stars to temperatures in the neighborhood of 50°K. The sensitivity of stratospheric instruments is inadequate to observe cooler dust clouds. Mapping and studying these extended, low surface brightness, objects requires a medium size (1 meter) cryogenically cooled telescope for maximum sensitivity. These regions are likely candidates for the initial steps of star formation through gravitational collapse and play an important role in the formation of interstellar molecules. A number of categories of stars exhibit an "infrared excess" at 10 microns. This appears to be due to circumstellar dust shells formed from material condensed in the stellar envelope. This material radiates thermally, primarily in the 5 to 50 micron region. Emission peaks, most probably due to silicates, have been identified in the 10 to 20 micron windows. Studies at moderate spectral resolution from above the earth's atmosphere are required in the 5 to 50 micron region to determine the composition of the dust, the mechanisms for its manufacture, and the way it is eventually

dispersed into interstellar space. This requires a low or medium resolution infrared spectrometer mounted on a large uncooled telescope.

HI AND HII REGIONS AND PLANETARY NEBULAE

Infrared line emission serves as an important cooling mechanism in the energy balance of both the general interstellar medium (HI regions) and diffuse and Planetary nebulae (HII regions). Present theoretical models utilize forbidden line emission processes that radiate in the 10 to 100 micron region, hence observations of this line emission are required to help verify the credibility of such models. Studies of the forbidden transitions are particularly powerful in determining physical parameters such as temperature, density, abundances, etc. Ground-based observations are limited to the few very bright sources. This work is best done using a cooled telescope, but can be accomplished from the warm telescope as well. The high resolution capability of the large warm telescope will allow study of the small-scale spatial structure that is known to exist, but poorly understood, in HII regions. The capability for emission line detection coupled with high spatial resolution will be an especially powerful tool for this purpose.

GENERAL

Infrared Survey

Approximately 100 objects have been discovered by stratospheric observations at 100 microns and covering a relatively small fraction of the sky. This list of objects has practically no overlap with the Cal Tech 2 micron catalog. The infrared sky is totally different from the optical and near infrared sky. An infrared survey requires a small (30 to 50 cm) cryogenically cooled telescope with multiple broad band detection systems covering the spectral range 10 microns to 300 microns. It should be a sortie "kick off" experiment with a lifetime of 3 to 6 months.

STELLAR ABUNDANCE AND STRUCTURES

Late-type Stars and Variables

Late-type stars and variables (spectral types K4 and later) have temperatures less than 4000°K. Under these conditions, the light elements, H, C, N, D, Si, etc., have strong tendencies to form diatomic molecules such as CO, DH,

NH, SiO, etc. The ability to observe, at one time, all the vibration-rotation bands of these molecules can provide an enormous amount of information on the evolutionary state, isotopic ratios, and the thermal and mechanical structure of the atmospheres of such objects. Unfortunately, because the molecules are light, the bands cover very wide ranges of the specturm, most of which cannot be observed through the atmosphere because of absorption by CO_2 and H_2O. For example, only the P-branches of the $\Delta V = 1$ OH bands can be observed from earth. The ability to observe the Q and R branches from the Space Shuttle would allow definitive values to be placed on the conditions of non-LTE in the stellar atmosphere, which, in turn, would permit much better explanations for certain anomalous isotope ratios in these stars. In turn, these isotope ratios can provide a direct measure of the evolutionary state of the star by means of the known properties of the CNO bicycle.

Early Type Stars

Since early type stars are quite faint, they must be observed outside of the atmosphere. Observation of the near infrared lines of hydrogen and helium will serve to show non-LTE effects when compared with observations of the visible lines. These stars can also be used as light sources for measuring extinction and the intensities of the interstellar fine structure lines.

PROTOSTARS AND PLANETARY SYSTEM FORMATION

Some systems of stellar-like objects and dust which have been seen to undergo structural changes over short time scales may be protostars, perhaps with attendant planetary systems, in the process of formation. Such objects would almost certainly emit the bulk of their radiation in the infrared. Study of these objects requires the high spatial resolution throughout the far infrared which is obtainable by a large (3 meter) telescope.

SOLAR PHYSICS

It has recently been discovered that the apparent brightness temperature of the solar disk decreases into the infrared and begins to increase once more towards the microwave region. A complete plotting of this phenomenon, impossible from earth or near-earth, would go far towards providing a definitive solution to the problem of the continuum opacity in stellar atmospheres of many types.

It is also important to note that planets shine in the near infrared by reflected sunlight. In order to interpret planetary observations, then, it is essential to have detailed knowledge of the solar spectrum incident on these planets and,

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for operational effectiveness, the spectrum should be obtained with the same instrumentation that provides the planetary spectra.

PLANETARY ATMOSPHERES AND SURFACES

The coupling of radiation to a planetary atmosphere is dominated by molecular processes and, furthermore, the temperatures tend to be low. It is therefore appropriate to investigate such atmospheres in the vibration-rotation bands of the pertinent molecules, which fall primarily in the infrared region of the spectrum. It is from such investigations that most of our current knowledge has been derived. However, investigations of certain molecules, particularly H_2O, are hampered by the presence of the same molecules in the earth's atmosphere. Balloon and aircraft altitudes are insufficient to remove completely the atmospheric effects. Furthermore, the apparent strengths of many of these bands, particularly CO_2 in Venus and H_2O in Mars, show anomalous variability which must be monitored continuously if we hope to understand the radiative properties of these planets. The Space Shuttle offers the most cost-effective way of doing this.

Planetary surfaces are a more difficult problem, because the mineral absorptions are sensitive to the presence of impurities. However, detailed investigations have already demonstrated the existence of liquid water on or in the surface of Mars and there is every reason to believe that broader-band coverage, as is available from the Space Shuttle, will provide more detailed information on the properties of planetary surfaces. It is also pertinent to note that the same arguments hold true for planets with dense cloud cover, such as Venus and Jupiter, wherein it is clear that the determination of the cloud constitution demands much wider and more accurate spectral coverage than has heretofore been available. The Space Shuttle can provide this.

SATELLITES AND ASTEROIDS

The remarks on planetary atmospheres and surfaces are equally pertinent for these minor solar system objects. At least one satellite (Titan) has a substantial atmosphere, showing significant CH_4 bands. Unfortunately, the telluric CH_4 provides strong interference with the observation of the Titanian CH_4. The Space Shuttle will obviate this effect.

The ability to observe asteroids over a wide wavelength region will go far toward providing a solution to the problem of the origin of the asteroid belt because it will be possible to make definite statements as to the mineralogical properties of these objects.

COMETS

Comets shine both by scattered sunlight and by emission, the emission coming largely from diatomic molecules in the comet's tail. In many instances, these lines are blanketed by telluric absorption and emission and it is most important to obtain cometary infrared spectra in regions free from telluric interference. The Space Shuttle will permit major strides to be made towards understanding these mysterious visitors to the solar system.

ZODIACAL LIGHT AND GEGENSCHEIN

The dust in the solar system, observed as the zodiacal light, is distributed as an oblate spheroid with its major axis along the ecliptic. The structure and origin of the dust may be similar to that of the dust observed in circumstellar shells. The infrared observations should give the solar system distribution and the spectral features may yield information about composition and size distribution.

RECOMMENDATIONS FOR FUTURE ACTIONS REQUIRED TO IMPLEMENT IR SORTIE MISSIONS

INTRODUCTION

As noted above, the infrared astronomy discipline is relatively new and is rapidly developing. In the past few years a rapidly expanding variety of observations has contributed extensively to the understanding of the astronomical phenomena discussed in Section 2. Startling results have been obtained with first-generation instruments and techniques, still in their infancy, used on existing ground-based telescopes, from balloons, and aircraft. In order to implement sortie missions in infrared astronomy, continuing research is required, using ground-based and sub-orbital facilities, that will expand the existing data base and prepare for the most effective scientific utilization of each sortie flight. Existing instrumentation for detection and spectral analysis of infrared radiation must be improved in sensitivity and extended in wavelength coverage. Designs of telescopes optimized for the infrared must be developed.

SRT

A vigorous SRT program must be pursued for instrumentation development. The techniques presently in use are crude, relatively insensitive, and require

high levels of maintenance and in-flight adjustment. A wide variety of techniques must be improved and explored in this decade using ground-based telescopes, balloons, and aircraft. Specific instrumental devices requiring development include improved detectors, far-infrared narrow-band filters, imaging devices, upconversion and heterodyne techniques, and high resolution spectral analyzers.

Line spectroscopy beyond 30μ has not yet been achieved for objects fainter than the sun and moon. It appears that the most promising approach to accomplish this objective is the application of one of the various interferometric techniques for spectral analysis, including the Michelson, Fabry-Perot, and Lamellar grating devices. These techniques are being explored in the aircraft and balloon programs. The approaches need to be evaluated in order to develop shuttle instrumentation capable of meeting the scientific objectives in the 1980's.

Support for a very large ground-based IR telescope is highly desirable. It is noteworthy that no telescope, including ground-based, has been designed from the beginning for optimum performance in the infrared. Ground-based telescopes currently used for infrared research mostly have been modified from existing optical telescopes, so that the ultimate sensitivity in infrared telescopes has not been realized. As a consequence, for instance, it has been possible to make a 28-inch telescope more sensitive at 10 microns than the 200 inch at Mt. Palomar. Experience gained in design and experimentation with an IR optimized, ground-based telescope will be of great value in proving design concepts for a high performance, low cost shuttle telescope.

The 91-cm Airborne Telescope, to be placed in operation in the NASA C-141 next year, will be an important source of supporting scientific research. In addition, it should be used as a test bed for in-flight evaluation of new instrumentation and as a means for developing infrared observing and operational techniques applicable to the shuttle enviroment.

A laboratory spectroscopy program is required to obtain f-values in the 1 to 5 micron spectral region. These data are needed for proper interpretation of the high resolution line spectroscopic observations that are expected from sortie missions and which are beginning to be obtained from the ground. As a parallel effort, theoretical work needs to be pursued to help explain IR observations and to calculate the wavelengths and strengths of the expected atomic and molecular transitions in the far infrared.

Cryogenic techniques must continue to be developed for application in the sortie missions. Some materials research is required to permit design of structures and mechanisms, such as a wobbling secondary capable of operating continuously in a space cryogenic enviroment.

STUDIES

Studies are required primarily in the area of infrared telescope design. The spectral region covers 10 octaves of wavelength, versus only 3 octaves for the UV and optical regions, and includes a great variety of astronomical sources requiring widely varying types of detectors and instrumentation. It is necessary to thoroughly investigate the trade-offs between a large, warm, telescope and a smaller, cryogenically cooled, one for the range of different astronomical problems. These trade-offs have not yet been fully examined but are required for proper design of a scientific cost-effective infrared shuttle facility.

There is a strong recommendation that the 3-meter, ambient temperature telescope planned for the infrared shuttle facility be a lightweight telescope operable under one g. The telescope should be capable of operation on the ground for pre-flight integration and test of instrumentation and also for ground-based astronomical observations during periods between sortie flights. The advantages of this concept include:

- Cost-effectiveness — The telescope can be tested on the ground without expensive facilities.
- Extensive body of astronomical observations accrued when not used on shuttle.
- If used in a "simulated" sortie mode on the ground, will permit the development of efficient operational procedures to maximize efficiency in orbit.

Feasibility and definition studies of this telescope should start quickly because of their impact on the basic conceptual design of the infrared shuttle facility.

FUTURE PLANNING ACTIVITIES

Planning activities are essential to develop a well integrated and properly scoped program culminating in the series of infrared shuttle sortie missions that are proposed. At present, the only cryogenically-cooled telescopes developed for IR astronomy include one in the Lear Jet and those used in rockets, as well as a balloon-borne radiometer. Support for work in this area should be pursued and extended to balloons where greater sensitivity can be achieved by taking full advantage of the low infrared flux background at 30 km altitude. These small cooled telescopes, which would actually be used for astronomical observations, can provide information on the design and operation of a cryogenically cooled shuttle telescope. Programs supporting this work must be coordinated

and organized for the development of the instrument technology needed for shuttle flights. Information on the behavior of cryogenics under zero g, however, must be obtained through flight experience. Therefore, plans should be made for providing a flight opportunity to test a prototype cryogenic system, perhaps on a technology satellite.

POTENTIAL CONTRIBUTIONS WHICH THE SORTIE MODE CAN MAKE OBTAINING THE GOALS AND OBJECTIVES FOR INFRARED ASTRONOMY

All of the infrared astronomy objectives benefit from the elimination of atmospheric absorption of radiation throughout most of the 1 to 1000 micron range. Many objectives benefit from the elimination of atmospheric radiative emission and from the elimination of turbulence. These benefits result from any mode of space operation. Those listed below are more closely associated with the sortie mode.

- The sortie mode permits use of a relatively inexpensive 3-meter telescope, larger than any existing balloon-borne or airborne telescope. The larger aperture provides faster data collection as well as increased resolving power. This instrument is ideal for far IR observations, which are not limited by radiation from the telescope, such as high spatial resolution mapping of extended sources and high spectral resolution line spectroscopy. Access to instruments for repair or replacement is possible during or between flights.

- The sortie mode permits use of a 1-meter cryogenically cooled telescope which enhances broad-band study of faint and of extended objects in the 5 to 1000 micron range. This instrument is particularly well-suited for Fourier spectroscopy in the far IR. Cryogen replacement and modifications can be made between flights. New sets of instruments may be added between flights. A lifetime of 30 days for a solid nitrogen cryogen would not require an advance in the state of the art. Liquid helium cooling for 30 days in zero gravity may be feasible in a few years.

- The sortie mode provides manned attendance of monitoring instruments and equipment at the focal plane of the warm telescope. Manned attendance provides a flexible response to unexpected problems and thus improves the reliability of the system or, alternatively, permits the use of more complicated systems such as a high resolution spectrograph. The possibility of saving an experiment from an unexpected problem contributes to the achievement of all of the sortie-related objectives, and results in increased data return.

- The sortie mode can be used to study the cosmic background radiation by use of a small, liquid helium cooled, wide field telescope extended from the shuttle.

- The long observation periods aboard the shuttle sortie mode provide the flexibility for observing time varying phenomena.

SORTIE MISSION TITLES FOR CHARACTERISTICS IN APPENDICES A AND B

INFRARED ASTRONOMY MISSION

Flight of 3-meter infrared and 1-meter cooled infrared telescopes.

MAPPING AND SPECTROSCOPY OF COSMIC BACKGROUND RADIATION

This instrument is small and could fly along with the mission above or could accompany an experiment from another discipline.

MULTIBAND SURVEY OF INFRARED SOURCES

This would be a 3 to 6 month free flyer. It would be a small portion of a shuttle payload and therefore compatible with a number of missions.

OUTLINE OF THE PROPOSED TOTAL FLIGHT SCHEDULE FOR INFRARED ASTRONOMY FACILITIES FLIGHTS

1979-1985 2 flights per year, each as long as possible. It is strongly urged that sortie mission lengths be extended beyond 7 days as early as possible.

1986-1990 During this period, transfer of the infrared facilities to a permanent space station is anticipated. Total observing time is expected to increase from 2 months per year by 1986 to perhaps 6-12 months per year by 1990. The facilities would be operated and serviced from the space station. If a space station is not available for this purpose, the sortie flights should be increased to provide the desired observing time.

APPENDIX A

APPENDIX A

DISCIPLINE AREA

IR Astronomy

SORTIE TITLE

Large Aperture Infrared Telescope. This facility may be on the same Sortie pallet as the cooled telescope described below in Appendix B. They are separated in this description because the cooled telescope places more stringent requirements on the shuttle.

REASONS THAT THE SORTIE MODE IS PREFERRED OVER OTHER MODES

- The sortie mode permits modification of the telescope and attached instrumentation between flights which allows greater versatility at reduced cost.
- The experimenter or payload specialist will have access to instruments near the focal plane which permits critical adjustments of the detectors and spectrometers throughout the observing period.
- The payload specialist can verify the acquisition of desired objects through his superior ability to recognize star patterns.
- The presence of trained men aboard the shuttle provides the greatest possible versatility in coping with unexpected problems, particularly if EVA's are allowed for emergency repairs.

REQUIREMENTS WHICH THE MISSION PLACES ON THE SHUTTLE

- Length of flights — 7 to 30 days, as long as possible is desired.
- Orbit — Moderate aititude, nominally 400 kilometers. Any orbital inclination is acceptable for the early flights.

  Studies should be made to identify optimum orbits, particularly concerning near-earth debris which would contribute to the thermal noise.

- Data requirements — A real-time, continuous, telemetry link between the shuttle observatory and the scientific ground control is needed. The bit rate required for the 3-meter telescope is 15 KB/sec continuous and 100 KB/sec for short term rapid data dumping. If the cooled telescope is on the same pallet the total bit rate requirements are 25 KB/sec continuous and 200 KB/sec short term. Uplink and downlink voice communication is needed.

- Role and number of personnel in orbit — 2 pilots; 1 mission specialist, who assists in operation of telescope; 1 payload specialist for 3-meter telescope. Recommend accomodate at least one or more appropriately, two extra crew members for 30-day mission.

- Stabilization and Pointing — The shuttle is expected to provide ± 0.5 stabilization. The 3-meter telescope will be independently stabilized to ± 1 arcsecond. Stabilization by-products which cause contamination of optical surfaces, resulting in increases in thermal background, or which produce infrared absorption, such as water vapor, are unacceptable. Stabilization of the shuttle is expected to require controlled moment gyros to minimize contamination.

- Power and Thermal — 3 KW are required for the 3-meter telescope and instruments during actual operation in orbit.

- Weight and Volume — This needs to be investigated more thoroughly. The 3-meter telescope may weight as much as 10,000 kg and occupy a volume of about 36 cubic meters.

- Extra Vehicular Activity — EVA's may be required for emergencies only. Studies should be made, however, on the cost-effective use of EVA for a one-time operation, rather than a fully automatic operation, such as the initial deployment of a boom.

- Correlative Measurements — Correlative measurements may be made with ground-based instruments but are not expected to place special requirements on the shuttle.

- General Support Equipment — An on-board computer is needed for telescope control and data handling.

- Documentation — The shuttle managers must provide an experimenter's handbook describing the shuttle interfaces and the procedures required to obtain design approval and meet testing and interfacing schedules. The telescope managers must provide documentation to experimenters

describing interfaces to the telescope for detectors spectrometers and other instrumentation as well as the procedures and deadlines for flights. The experimenters may be required to certify their hardware for certain vibration, vacuum and temperature conditions.

- Special operating constraints — The open bay of the shuttle is to point away from the sun and earth as much as possible.

- Contamination — No fuel cell purges or attitude rocket firings are to be made during the observing period. Deliberate venting of gases other than helium and nitrogen must be avoided.

POLICY AND PROCEDURE CHANGES

Documentation for "man-rating" of equipment should be reduced to the minimum required to assure the safety of the crew in the shuttle environment. The attitude of program management must be that the experimental payload is the prime mission for the flight.

MAGNITUDE OF THE SORTIE USER COMMUNITY

Infrared astronomy is a rapidly growing field. Nearly 50 groups responded to a recent announcement of flight opportunities on the 91 cm Airborne Infrared Telescope. The advantages of the shuttle sortie telescopes are expected to appeal to an even broader range of astronomers.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

The attitude of facility management is very important in how effectively the facility will be used. Not only must the NASA interface with the user community be user-oriented, but also the overall shuttle management must be oriented to the problems of the users.

The interface with the user community would be most simple and effective if one NASA center were assigned complete responsibility for the IR astronomy facility. All contacts between the experimenters and NASA would be handled by one office at that center. That office would coordinate its activities with Headquarters and other centers involved. This would minimize confusion and expense to the user and encourage participation by the best researchers.

RECOMMENDATIONS FOR FUTURE ACTIONS

A vigorous program of instrumentation development must be pursued. Advances are sought in detectors, far-infrared filters, imaging devices, upconversion and heterodyne techniques and spectral analyzers.

Strong support of ground-based, airborne and balloon-borne astronomy is needed to supply the design concepts for the shuttle telescope, to define the most critical astronomical objectives, and to provide test beds for advanced instrumentation.

Efforts in laboratory infrared spectroscopy and theoretical astrophysics must be supported in order to provide a basis for interpretation of observational data.

Studies are required for the design of infrared telescopes. The tradeoffs between larger diameter and lower temperature optics must be examined for the various types of astronomical objectives anticipated. The effects of contaminants in the shuttle enviroment must be examined in detail.

Cooled telescopes must be built and tested to improve the technology and to obtain operational experience with them.

Development and ground testing of the 3-meter IR telescope for the shuttle must be pursued in preparation for sortie missions in " '79 or '80".

Future planning should include continued discussions between NASA scientists and potential sortie experimenters in the astronomical community.

APPENDIX B

APPENDIX B

DISCIPLINE AREA

IR Astronomy

SORTIE TITLE

Cooled Infrared Telescope.

REASONS THAT THE SORTIE MODE IS PREFERRED OVER OTHER MODES

- The sortie mode permits modification of the telescope and attached instrumentation between flights which allows greater versatility at reduced cost.
- Cryogens must be replaced at intervals which are compatible with the sortie mission lengths.
- The payload specialist can verify the acquisition of desired objects through his superior ability to recognize star patterns.
- The presence of trained men aboard the shuttle provides the greatest possible versatility in coping with unexpected problems, particularly if EVA's are allowed for emergency repairs.

REQUIREMENTS WHICH THE MISSION PLACES ON THE SHUTTLE

- Length of flights — 7 to 30 days, as long as possible is desired.
- Orbit — See Appendix A. Nominally 400 kilometers. Any orbital inclination is acceptable for the early flights.
- Data requirements — A real-time continuous telemetry link between the shuttle observatory and ground control is needed. The bit rate requirement for the cooled telescope is 10 KB/sec continuous and 100 KB/sec for short term data dumps. Uplink and downlink voice communication is required.
- Role and number of Personnel in orbit — 2 pilots; 1 mission specialist; 1 payload specialist.

- Stabilization and pointing — Requirements are the same as in Appendix A. The shuttle is expected to provide accuracies to within $\pm 0.5^c$ to $\pm 6.0°$ arcseconds. Stabilization of the shuttle must not use rocket firings or other gas expulsion because of contamination of cold optical surfaces.

- Power and Thermal — 2 KW are required for cooled telescope and instruments during orbital operation. Thermal radiators must face away from telescope.

- Weight and volume — The cooled telescope will weight about 5,000 kg and occupy about 5 cubic meters.

- Extra-Vehicular Activity — EVA's may be required for emergencies only.

- Correlative Measurements — May be made with ground-based instruments, but are not expected to place special requirements on the shuttle.

- General Support Equipment — An on-board computer is needed for telescope control and data acquisition.

- Documentation — The shuttle managers must provide an experimenter's handbook describing the shuttle interfaces and the procedures required to obtain design approval and meet testing and interfacing schedules. The telescope managers must provide documentation to experimenters, describing interfaces to the telescope for detectors spectrometers and other instrumentation as well as the procedures and deadlines for flights. The experimenters may be required to certify their hardware for certain vibration, vacuum and temperature conditions.

- Special Operating Constraints — The cooled telescope must not point closer than about 45° from the sun and 30° from the earth. If venting of a condensable gas must be performed during the observing period, the telescope will have to be closed during the venting.

- Contamination — This problem is especially serious for a cold telescope because a layer of material can build up on the mirror. This material would have its own characteristic absorption spectrum and would render observation inaccurate. Further study of the allowable ambient pressure is required. It is clear that no deliberate venting should be allowed. No fuel cell purges or altitude rocket firings can be made while the telescope is exposed.

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APPENDIX C

APPENDIX C

DISCIPLINE

Infrared Astronomy

SORTIE TITLE

Mapping and Spectroscopy of Cosmic Background Radiation

REASONS THAT THE SORTIE MODE IS PREFERRED OVER OTHER MODES

The sortie mode permits retrieval of the instrument for recalibration after the measurements (considered important for this type of work) and for subsequent re-use. State-of-the-art liquid helium hold times are compatible with sortie flight times of up to 30 days. This instrument could be flown as a free-flyer.

REQUIREMENTS WHICH THE MISSION PLACES ON THE SHUTTLE

These requirements are for an attached instrument. If it is a free-flyer the requirements are the same as for the Multiband Survey instrument.

- Length of flights — Seven days is adequate. Longer would be beneficial.
- Orbit — Nominally 400 KM altitude. Inclination to be determined for maximum sky coverage, probably not too critical.
- Data Requirements — 1 KB/sec continuous downlink rate with occasional short 100 KB/sec rate.
- Role and Number of Personnel in Orbit — Requires attention only during deployment and stowage. Crew size determined by the main mission.
- Stabilization and Pointing — If shuttle is stabilized to 0.1° further pointing may not be required. Otherwise and auxilliary gimbals will have to be provided for the instrument.
- Power and Thermal — Less than 0.1 kwatt required. 30 VDC is satisfactory. Instrument will carry its own cryogens.

- Weight and Volume — 200 kgms weight and 1 cubic meter volume including extendable boom.

- Extra-Vehicular Activity — EVA may be needed for emergency but not for the normal operation.

- Correlative Measurements — None on shuttle.

- General Support Equipment — Extendable boom needed to hold the instrument at roughly 30 meters from the shuttle.

- Documentation Requirements — The instrument should be given documented tests for vibration, g-load. Experimenters manual on shuttle interfaces required.

- Constraints — Instrument should not point within 45° of sun or 30° of earth.

- Contamination — No venting of anything but helium permitted during this experiment. Controlled moment gyros needed for attitude control.

POLICY AND PROCEDURE CHANGES

Same as stated in Appendix A.

MAGNITUDE OF THE SORTIE USER COMMUNITY

Roughly two dozen scientists are now working on background experiments. Significant growth is not anticipated.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

As stated in Appendix A.

RECOMMENDATIONS FOR FUTURE ACTIONS

Balloon-borne and rocket launched experiments should be continued to optimize the instrumentation for this research and to better define the objectives.

APPENDIX D

APPENDIX D

DISCIPLINE

Infrared Astronomy

SORTIE TITLE

Multiband Survey of Infrared Sources

REASONS THAT THE SORTIE MODE IS PREFERRED OVER OTHER MODES

The Multiband Survey instrument will be a free-flyer for 3 to 6 months. Sortie mode permits on-board orbital checkout prior to deployment. It may permit retrieval although this is not essential.

REQUIREMENTS WHICH THE MISSION PLACES ON THE SHUTTLE

- Length of flights — Not important. Deploy quickly.
- Orbit — Nominally 400 KM.
- Data Requirements — Negligible. Communications are self contained.
- Weight — 200 kgms, Volume — 1 cubic meter.
- EVA — Emergency repair.
- Correlative Measurements — None on shuttle.
- General Support Equipment — Release mechanism and on-board test equipment.
- Documentation — Experimenters manual on shuttle interfaces is needed.
- Special Constraints — None.
- Contamination — No purging or venting of anything but helium during deployment and on-board check-out of instrument. This should take only a short time, perhaps 60 minutes.

POLICY AND PROCEDURE CHANGES

See Appendix A.

MAGNITUDE OF THE SORTIE USER COMMUNITY

Numerous groups involving at least 30 astronomers have proposed infrared IR surveys from space. The survey will be of general usage in the astronomical community.

RECOMMENDED APPROACHES FOR INTERFACING WITH THE USER COMMUNITY

See Appendix A.

RECOMMENDATIONS FOR FUTURE ACTIONS

See Appendix A.

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